

**RECONNAISSANCE DATA
RECORDING STUDY
FINAL TECHNICAL REPORT**

by

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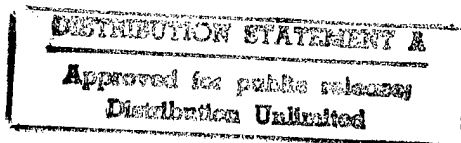
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13. ABSTRACT (Maximum 200 words) Synectics Corporation conducted a study of recording technologies with the potential to meet the requirements for future reconnaissance imaging systems. We also performed an assessment of potential "dual-use" applications of the Sony DVR-2 magnetic tape recorder and the S/TODS, an optical disk advanced development program. The purpose of these two tasks was to prepare a technology road map and a prototype development plan for a recording system that can meet the continuing evolution of imaging sensors. The key finding resulting from this study was that there is a tremendous commercial demand for recording technology that can cost effectively be applied to the military reconnaissance mission. The technology road map and prototype development plan prepared under this study builds upon the "dual-use" application of commercial recording media and uses a system concept embodied in commercial Hierarchical Storage Management (HSM) systems. An HSM solution provides a system concept that isolates reconnaissance sensors from the changes in the media technologies, and allows recording systems to be reconfigured to meet particular sensor demands, such as changes in data rates, sensor formats, and number of sensors, distributing the recording components within the platform, and may other positive solutions to the reconnaissance recording problem			
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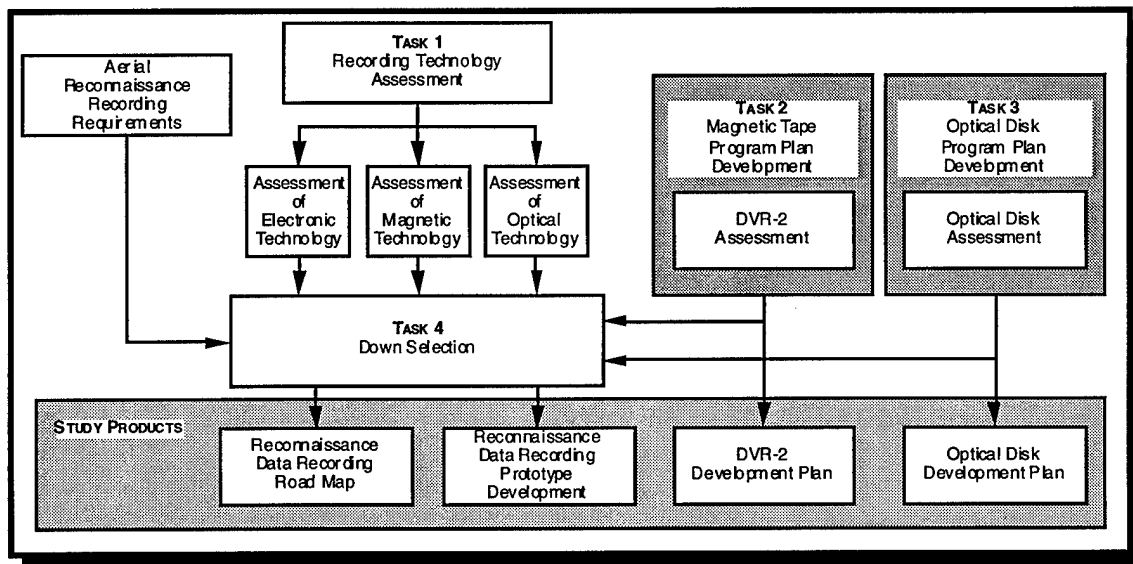
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1.0 INTRODUCTION

This is the Final Technical Report for a Naval Air Warfare Center, Aircraft Division, Small Business Innovative Research (SBIR) effort, Contract No. N62269-95-C-0051, conducted by Synectics Corporation. This Final Technical Report is organized in accordance with Exhibit 1 and follows the tasks specified in the Statement of Work (SOW) for this effort.

Exhibit 1 SBIR Study Flow



1.1 CURRENT STATUS

The current standard for a reconnaissance recording system is the digital magnetic tape recorder. This recording approach has been the recording technology of choice because of cost availability, volume, high recording rates, ability to function in the operational

environment of a tactical aircraft, and because it provides a convenient method for removing data from the collection vehicle. However, there are limitations such as: limited operating temperature and humidity ranges, the necessity of pre-conditioning the tape prior to and during operation, limited data access speeds, and the traditional need to reduce space, volume, and power.

From the sensor perspective there is a continuing demand to increase the possible field of view and the resolution, and measure all of the spectral characteristics of each collected sample. Sensors can be designed to collect information from horizon to horizon in all directions, and they can be implemented with the highest resolution sampling system available.

An advanced multispectral system, the Airborne Visual/Infrared Imaging Spectrometer (AVIRIS), has recently been developed by the Jet Propulsion Laboratory at the California Institute of Technology. AVIRIS is a mechanical scanning pushbroom system designed to acquire 614 pixels in each scan line, in addition to acquiring the spectral information from 224 discrete spectral bands for each pixel. These and other imaging sensors will continue to evolve and will continue to require greater recording capacity.

Other non-literal sensors such as Synthetic Aperture Radar (SAR) systems, which provide day/night, all weather capability, will continue to evolve with technology advancements. These new classes of sensors may require greater data recording capabilities than the general types of imaging sensors. There is one salvation for this continuous demand for greater data recording capacity and throughput, and that is data compression. However, data compression is only a short term or temporary fix because sensor types will continue to increase and the demand for data recording will always be

there. This is not intended to imply that data compression is not important. It is very important and must be pursued on a level comparable to that of data recording.

The demands on reconnaissance data recording will continue to increase, and unless there is a reconnaissance data recording technology road map that can take advantage of current commercial or "dual-use" technologies, the problems of reconnaissance data recording will always require study and analysis.

1.2 STUDY APPROACH

Exhibit 1 provides an overview of how the study was conducted and the interrelationships between the various tasks.

The SOW identified four major tasks:

- ☐ Task 1 — Reconnaissance Data Recording Technology Assessment
- ☐ Task 2— Magnetic Tape Program Plan Development
- ☐ Task 3 — Optical Disk Development Plan Development
- ☐ Task 4 — Down Selection

Prior to the conduct of this study, we developed a set of Aerial Reconnaissance Recording Requirements to be used during the performance of Task 4. The results of analysis and assessments of the DVR-2 and S/TODS (Strategic/Tactical Optical Disk

System) systems performed during Tasks 2 and 3 were integrated with the results of Task

1. Four products resulted from the performance of Tasks 2, 3, and 4:

- ☐ DVR-2 Development Plan
- ☐ S/TODS Development Plan
- ☐ Reconnaissance Data Recording Road Map
- ☐ Reconnaissance Data Recording Prototype Development Plan

The Final Technical Report is organized into sections as they relate to the flow of the study illustrated in Exhibit 1.

- ☐ **SECTION 2, EXECUTIVE OVERVIEW** — highlights the results of this effort and gives a top level presentation of the road map and prototype development.
- ☐ **SECTION 3, REQUIREMENTS** — discusses the set of requirements developed for conducting this study.
- ☐ **SECTION 4, RECORDING TECHNOLOGY ASSESSMENT** — highlights the three basic recording technologies: electronic, magnetic and optical. Each technology is assessed in terms of meeting the requirements of a reconnaissance recording system.
- ☐ **SECTION 5, DVR-2 ASSESSMENT AND DEVELOPMENT PLAN** — an analysis of the Sony DVR-2 and a discussion of the practicality of modifying this system for an aerial reconnaissance recording system.
- ☐ **SECTION 6, S/TODS ASSESSMENT AND DEVELOPMENT PLAN** — an analysis of the Rome Laboratory advanced development model of the

S/TODS and a discussion of the practicality of modifying this system for an aerial reconnaissance recording system.

- ❑ **SECTION 7, DOWN SELECTION OF RECORDING TECHNOLOGIES** — details the analysis and logic for the creation of a Reconnaissance Data Recording Road Map and the development of a Reconnaissance Data Recording Prototype Development.
- ❑ **SECTION 8, RECONNAISSANCE DATA RECORDING ROAD MAP** — details the actions and investments necessary to develop a technology-survivable reconnaissance recording system for aerial reconnaissance.
- ❑ **SECTION 9, RECONNAISSANCE DATA RECORDING DEVELOPMENT PLAN** — outlines a development plan for a prototype reconnaissance recording capability.

2.0 EXECUTIVE OVERVIEW

Reconnaissance data recording technology should be the leading reconnaissance technology since each reconnaissance platform must have an onboard recording capability. The reconnaissance data recording system should be in place, tested, evaluated, and proven before any sensor or sensor suite is considered. However, the sensor recording capability is usually the last component of any reconnaissance system to be considered.

Magnetic tape is the current standard technology for reconnaissance recording. However, the current systems are those specially developed for military use, and although they are cost available, there is no adequate research and development program to address the limitations of these systems. This is not unique; many military systems are essentially "one of a kind" and are not able to take full advantage of commercial or dual-use technologies.

This study effort conducted an exhaustive review (Appendix A) of the current dual-use recording technologies. One of the technology thrust areas that cuts across all recording technologies is support of the recording needs of the Personal Data Assistant (PDA). The PDA demand is for low cost, large volume, low power, and for a very small footprint or space recording system. The vendor that develops the most robust PDA has a potential sales volume of a million units, so obviously, there is a tremendous market for recording technology in the commercial area. The type of media be of any form, but the performance and operational requirements must be met. The operational environment of a PDA is similar to that of a tactical aircraft.

The obvious conclusion of this study is to use these rapidly developing dual-use technologies, but a problem remains. How can these small, inexpensive, very high performance recording technologies be configured to meet the demands of a reconnaissance recording system? A similar problem was also encountered by the personal computer (PC) developers a few years ago. Their solution was to apply a concept referred to as a Redundant Array of Inexpensive Disks (RAID). The first RAID systems used an array of magnetic disks. In one RAID configuration (there are several levels of RAID) a single stream of data can be spread across multiple drives to increase the data recording rate. In another configuration, greater data survivability can be

provided, etc. This technology has been expanded to include magnetic tape and, more recently, optical disk vendors are using the concept.

Concurrent with the development of the RAID concept, other vendors were investigating the application of a recording technology that was developed about 15 years ago. This technology used a management or data processing system to manipulate different types of recording systems based upon the demands for different recording capabilities such as recording speed, access times, file sizes (sometimes the archival requirements are also considered), etc. This recording technology is referred to as Hierarchical Storage Management (HSM) (see Appendix B). HSM has had a tremendous resurgence because of the proliferation of recording technologies and the rapid evolution of these technologies. An HSM effectively isolates the system using the HSM from the changes in the media technologies, in addition to providing the capability to reconfigure the recording system to meet particular recording demands.

The conclusion of this study is to build upon the HSM concept for a reconnaissance recording system. An HSM can be tailored to meet specific reconnaissance requirements using a selection of recording technologies. This technical approach has the advantages of isolating the reconnaissance system from the tremendous growth in recording technology, but more importantly, it provides a solution for implementing a single recording system that can be reconfigured to meet different reconnaissance needs such as different platforms, different sensors, distribution of the recording systems within the platform, and many other positive solutions to the reconnaissance recording problem.

3.0 REQUIREMENTS

Exhibit 2 was compiled at the beginning of the study effort and served as a baseline set of requirements for conduct of the study. These requirements were coordinated with the government and represents a reasonable set of requirements.

Exhibit 2 Reconnaissance Data Recording Requirements

1.0 OPERATIONAL REQUIREMENTS	2.0 RECORDING REQUIREMENTS
1.1. Mission Profile	2.1. Recording rates without compression at least 250 megabits
1.1.1. Altitude: 100 to 65,000 ft	2.2. Compression Options
1.1.2. Vibration for unmanned & manned aerial vehicles	2.2.1. No Compression
1.1.3. Motion	2.2.2. With Compression
1.1.3.1. Angular Velocities: less than 270 degree/sec	2.2.2.1. DCT
1.1.3.2. Angular Accelerations: less than 860 degree/sec	2.2.2.2. DCPM
1.1.3.3. Linear Accelerations: less than 9 gravities	2.2.2.3. Others to be considered
1.1.3.4. Shock: less than 20 gravities	2.3. Data Sources
1.2. Vehicle: FA/18	2.3.1. ATARSS sensors
1.3. Volume: less than 3 cu ft	2.3.1.1. LAEO
1.4. Weight	2.3.1.2. MAEO
1.4.1. Recorder: less than 200 lbs	2.3.1.3. IR Wide
1.4.2. Media Transport Device: less than 30 lbs	2.3.1.4. IR Narrow
1.5. Temperature Ranges: -10 to +130 degrees F	2.3.1.5. AP G-73
1.6. Humidity: 100%	2.3.2. EO LO ROPS
1.7. Air Pressure	2.3.3. Other digital imaging sensors
1.7.1. Static: 19 psi to 15.7 psi	2.4. Total Storage: at least 1 terabit
1.7.2. Ranges: $\pm 10\%$	2.5. Error Rates: less than 1×10^{-10}
1.8. Dust: 0.3 ± 0.2 grams/cu ft	2.6. Data Transfer
1.9. Acoustic: less than 140 dB	2.6.1. Burst
1.10. Power	2.6.1.1. Rate: at least 500 megabits per sec
1.10.1. Nominal Voltage: +28 volt DC	2.6.1.2. Duration: no greater than 2 sec
1.10.2. Watts: up to 300 watts	2.6.2. Average: 250 megabits per sec
1.11. Cooling: not to exceed cooling inlet temperature of 45 degrees F at flow rate of 0.72	2.7. Data Access Time: any data within 5 min
1.12. EMI: MIL-E6051 and MIL-STD-461	3.0 SYSTEM REQUIREMENTS
1.13. Media Exchange Unit	3.1. Control Bus: MIL-STD-1553
1.13.1. Physical device: less than 1/2 cu ft and less than 20 lbs	3.2. Interoperability: ISO OSI model compatible
1.13.2. Non Volatile at least 6 months	
1.14. Warm up time: less than 5 minutes	
1.15. General Operating Environment: standard runway operations	

3.1 REQUIREMENTS ANALYSIS

Requirements are divided into three types: operational, recording, and system. Each will be discussed separately below.

3.1.1 OPERATIONAL REQUIREMENTS

Operational requirements describe the operational environment in which the recording system is to operate. These requirements describe an airborne environment, and there are four subsets of these operational requirements which can be improved through technology to meet future needs. These subsets are: volume, weight, power, and media exchange unit. Changing any one of these four will have the effect of improving the mission effectiveness of aerial reconnaissance system.

3.1.1.1 Volume

In any aerial reconnaissance system there is always a need to reduce the volume of a recording system. A smaller volume eases the constraints on the platform aeronautical parameters to improve platform maneuverability and allows other devices to be carried, such as other types of sensors which can collect a greater diversity of data, Electronic Counter Measures (ECM) equipment which increase the survivability of the platform, and other devices which can improve the reconnaissance mission.

3.1.1.2 Weight and Power

In any airborne platform there is always a need to reduce the weight and power requirements of a recording system. Lowering either one or both of these requirements will increase the duration of the reconnaissance mission and will increase the platform aerodynamics to increase the survivability of the mission

3.1.1.3 Media Exchange Unit

Throughout the development of digital recording systems there has been a constant evolution of different types of devices to transport the collected data from the platform to a surface data handling system. This evolution will continue to reduce the space, weight, and power requirements of the recording system and improve the overall system interoperability.

3.1.2 RECORDING REQUIREMENTS

The recording requirements developed for this study are based upon what those which are attainable with current recording technology. Specifically these requirements generally describe a high speed tape recording system, and all seven subcategories of requirements can be improved with the application of improved recording technology. There are six subcategories that will change as the recording technology changes: recording rates, data sources, total storage, error rates, data transfer, and data access. The seventh, compression options, may change but it is not affected by recording technology, and any improvement in compression can be applied without affecting the recording system.

3.1.2.1 Recording Rates

The maximum recording rate is dictated by the sensors. With improved sensors, and/or the addition of more sensors, the recording rates will have to be increased. Therefore the

recording rate will always be the highest that technology will allow for an airborne environment.

3.1.2.2 Data Sources

The data sources listed are those sources that are currently being used for the Advanced Tactical Air Reconnaissance System (ATARS). This sensor technology is about 10 years old (circa 1985). Current sensor technology is evolving towards farming type systems versus the ATARS pushbroom systems (i.e., the use of platform motion or scanning device to move a linear detector over the object to be imaged). These pushbroom systems constrain a reconnaissance mission. Framing systems, on the other hand, improve the collection options of a reconnaissance system but cause a tremendous increase in the recording rates. In addition there are other sensor technologies being developed that will also increase the requirement for higher recording rates.

3.1.2.3 Total Storage, Error Rates, Data Transfer, and Data Access

The total storage, error rates, data transfer, and data access requirements are also limited by current technology. Increasing each of these requirements will have an impact on improving the reconnaissance mission.

3.1.3 SYSTEM REQUIREMENTS

These requirements are derived from the current system standards being used. Changing these requirements to be compatible with other types of system requirements increases the system interoperability and reduces overall life cycle cost.

3.2 SUMMARY REQUIREMENT ANALYSIS

From a reconnaissance system effectiveness perspective, improving the operational requirements for space, weight, and power will have the greatest effect. The technology supporting the media exchange unit will continue to improve and will reduce the space, weight, and power requirements.

The key driving factor in the recording requirements will be the data sources which will continue to increase. Any reconnaissance mission occupies a location in space. That location in space is critical because conventional sensing technologies require line-of-sight, which implies that the target to be observed can observe the reconnaissance system. Therefore the most effective approach is to collect up to the maximum limits of the recording system. The limits of a recording system are defined by recording rates, total storage, error rates, data transfer, and data access.

4.0 RECORDING TECHNOLOGY ASSESSMENT

Currently there are three basic technologies for recording digital reconnaissance sensor data: electronic solid state, magnetic, and optical. The following provides a brief overview of the current technology status and an assessment of each technology.

4.1 ELECTRONIC SOLID STATE RECORDING

The capacity (storage per unit area) of electronic solid state memory recording technology has generally doubled every two to three years. However the technology to fabricate increased capacity is reaching the physical limits of the technology, and has reached the capital investment cost to develop a production facility to manufacture higher capacity components. Dynamic Random Access Memories (DRAM) and Flash Memory are the two basic electronic solid state technologies being pursued.

4.1.1 DYNAMIC RANDOM ACCESS MEMORY

The application of Dynamic Random Access Memory (DRAM) technology for reconnaissance systems has three critical limitations:

- ❑ *VOLATILITY*. DRAM recording technology requires continuous electrical power to preserve the recorded information. The volatility limitation requires consideration of two major components.

- ◆ Alternate Power Source. A DRAM recorder requires a battery or back power supply into any reconnaissance system. This adds more weight, space, and power to a system that requires minimum limits on these three parameters.
- ◆ Transport Device. The transport of data recorded by a DRAM storage system from a reconnaissance platform to another system will require a nonvolatile transport device. This is a duplication of recording capabilities and, to be effective with respect to weight , space, and power, the transport device should not be carried on the reconnaissance platform. This may limit the interoperability of the platform.
- ❑ *TOTAL RECORDING CAPACITY*. DRAM recording capacity per unit of volume has been increasing and will continue to increase with improved packaging techniques. However, this increase is orders of magnitude below magnetic and optical technologies.
- ❑ *COST*. DRAM cost per bit of storage has decreased over time, but not at the rate of magnetic and optical technologies.

4.1.2 FLASH MEMORY

Flash memory has been around for some time but is just now becoming popular because of increased chip storage capacity, reduced manufacturing costs, and demands for low power, low weight storage created by PDAs and other mobile computing devices. Flash memory is not only fast (with less-than-1-millisecond seek time), it is extremely reliable. Because it has a lower soft error rate than DRAM and is nonvolatile, flash memory is an ideal candidate for reconnaissance recording applications. Flash memory today has low

power consumption and offers survivability well beyond that of rotating media. It can survive a shock in excess of 1200 Gs and operate in temperatures ranging from -13° F to +167° F. Flash storage is also small (32 Mb chips should soon provide storage of 195 MB per cubic inch). Flash memory today is an ideal storage solution for reconnaissance systems except for price; current estimate is about \$300 per MB. However, price will probably continue to drop as manufacturing techniques improve.

4.1.3 ASSESSMENT OF ELECTRONIC SOLID STATE RECORDING

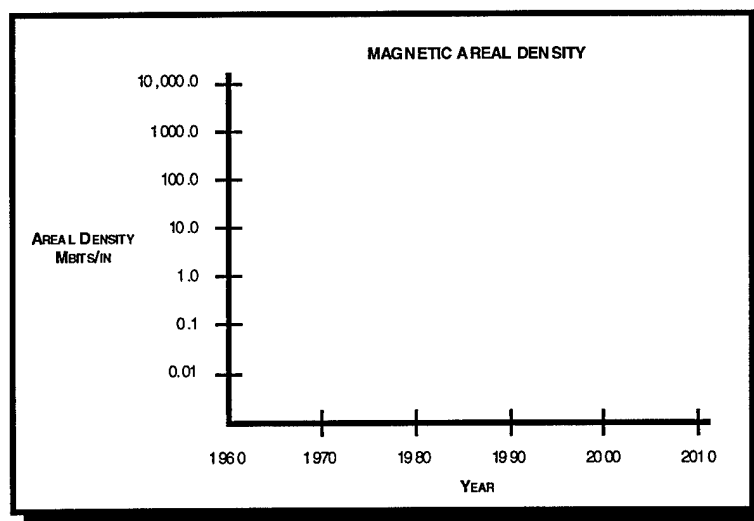
Assessment of electronic solid state recording found that it is, and will continue to be, the highest cost recording system as compared to other recording technologies. In the past cost reductions occurred as a result of increased storage density. However, the storage density of electronic solid state recording is reaching its limit. This limit is due to the very large amount of capital investment that is required to establish a potentially risky (with respect to product reliability) manufacturing capability. Access speeds of this technology will increase slightly and will only be slight above other competitive technologies.

4.2 MAGNETIC RECORDING

Magnetic recording technology has been the mainstay for recording systems throughout most of the information age. However, a major change which recently occurred in the magnetic recording media industry has been the invention of, as well as the implementation of, magnetoresistive (MR) heads. This technology has allowed for great

increases in aerial bit densities of magnetic recording media (see Exhibit 3). Today's trend, for the major commercial magnetic recording producers, is to leap toward the use of MR heads in their designs. Suppliers of these head types are becoming plentiful while suppliers of the old inductive head technology are beginning to fall off. Of course increased aerial bit density allows for increased storage capacity without an increase in physical size (e.g., 3.5" disk drives available in 1996 at 9 GB).

Exhibit 3 Magnetic Bit Density



4.2.1 MAGNETIC TAPE

Magnetic tape recording systems are growing quickly in capacity and, despite impressive improvements in hard disk storage, are keeping pace with magnetic drives. Quarter-inch cartridge (QIC) drives account for a majority (over 75%) of the installed base of all computer tape drives, and as time progresses more systems are changing over from the helical-scan and optical technologies. One unique attribute is that the QIC tape can be configured to be compatible with a wide range of application including a potential for

reconnaissance systems. Newer Digital Linear Tape (DLT) offers capacity, speed, extreme reliability, and is capable of operating in an aerial platform environment. The major drawback for the newer tape systems is record speed and access time. Substantial increases have been made in storage capacity and performance due to MR heads and the PRML Read/Write channel. This increased performance is also due to servo systems to position the heads across the tape width, thinner tape materials (allowing more tape length on the same physical reels), and new media (1600 Oe). Current tape technology provides for uncompressed capacities of over 48 GB per cartridge and data transfer rates of 60 MB/SEC.

4.2.2 MAGNETIC DISK

Magnetic disks are experiencing a tremendous up-tick in the rate of capacity growth. The present trend is a compound growth rate of 60% per year. This is superimposed on a price per Mb decrease of nearly 40% per year. These trends are due to fierce competition within the PC industry, fueling an even fiercer competition within the disk industry. The technology basis is the practical implementation of MR heads and the PRML Read/Write channel as discussed above. These two innovations have dramatically increased the amount of data that can be stored per square inch of disk space, and thus the capacity possible in a drive. Present technology allows eleven 3.5" disks to fit in a 1.63" high drive, and eight 2.5" disks to fit in a 0.49" high drive. On the near horizon is a transition to so called "pico" form factor heads. These will permit additional disks to be placed in the same form factors. Substrate improvements (e.g., use of glass or ceramics and improved aluminum) will permit thinner disks, further increasing the number of disks which can be placed within a drive. Currently available families of high-performance

3 1/2" drives rotate at 7,200 rpm and feature an aerial density of 564 Mb per square inch, a seek time of 8.6 ms.

4.2.3 ASSESSMENT OF MAGNETIC RECORDING

The continued improvements in magnetic read/write heads will follow the improvements in the partial response maximum likelihood (PRML) Read/Write channel. The PRML channel utilizes data detection techniques which significantly reduce the raw read error rates of magnetic recording media devices. Raw read error rates can be reduced by a factor of 50 to 300. Both the magnetic tape and magnetic disk drive industries have made substantial increases in storage capacity and performance due to MR heads and the PRML Read/Write channel. Other advances have occurred in each of these industries including digital servo systems and new media technology, so that the future focus will be on improving the device electronics to read and write data.

Improvements in access times for all of these memory types has been modest over time. In the case of disks and tape this is due to both the mechanical nature of these mechanisms as well as to some interrelated electrical issues. The mechanical problems are fairly easy to understand. To move something faster you need more power and will probably make more noise. It is not desirable to increase either of these features. In the case of disk drives, improved motors and bearings have allowed an increase of the normal spindle speed from 3,600 RPM (with 20 microinches of non-repeatable runout (NRRO) and an MTBF of 40,000 hours) in 1986, to 5,400 to 7,200 RPM in 1995 (with less than 6 microinches of NRRO and MTBFs of greater than 500,000 hours). Improved spindles, perhaps using fluidic bearings instead of ball bearings are expected to permit the use of 10,000 to 12,000 RPM spindles in 1996. A 12,000 RPM motor will permit, other

things being equal, a reduction in average access time to the neighborhood of 6.8 ms (from 8.8 ms now) for a high performance disk drive.

To overcome some of the above limitations, developers are focusing on the electronics to drive magnetic recording systems. Now the recording system developers are establishing a strong in-house digital processing capability to move more and more features from firmware to hardware. Strong analog and digital signal processor (DSP) capabilities are in high demand as designers of advanced magnetic recording systems place new priorities on developing faster data channel devices.

4.3 OPTICAL RECORDING

Optical storage has the potential of being the primary storage media for a reconnaissance system. It can perform in harsh operational environments such as those encountered in an aircraft or an unmanned aerial vehicle. The basic approach for optical technologies is to use a laser to record data and in some cases, but not all, to use a laser to read recorded data. There are two basic optical recording approaches—optical disk and 3-dimensional (3-D). There is sufficient physical separation between the laser and the recording media to tolerate the environmental conditions of an aerial vehicle. The 3-D approach is essentially a solid state approach with potentially no moving parts and can be fabricated to operate in environments harsher than an aerial vehicle.

4.3.1 OPTICAL DISK

Optical disk recording technology using a laser began in the early 1980s when CD audio disks became the dominate method of distributing and listening to high fidelity music. The introduction of the laser diode allowed the development of optical playback devices that could tolerate rugged consumer use. Also the 1980s witnessed the introduction of a more flexible optical recording concept of write-once-read-many (WORM). Currently the optical recording industry is pursuing the rewritable optical disk using a magneto-optical (MO) method of data recording. MO medium is composed of an alloy which often includes elements of terbium, iron, and cobalt. Receding data on an MO disk are essentially an optical-assisted magnetic recording. Data are recorded by using a combination of a laser to provide heat and a small local magnetic field. The laser elevates the temperature of the local medium slightly beyond the Currie point (approximately 200°C). At this elevated temperature, an external magnetic field can easily change the medium's magnetic orientation, Data readout uses polarized laser light. The stored magnetic domain causes the reflected laser light to rotate its referenced polarization angle. Data erasure is performed by reversing the recording process by using the laser to heat the medium and returning the magnetic domain back to its original orientation.

In contrast to the MO technique, a phase change rewritable (PCR) disk encases a thin chemical layer used for encoding the data. When heated by the laser, the chemical layer changes from an amorphous state to a crystalline state, changing the reflectivity differences which then can be read as 1s and 0s. The phase change recording process can be accomplished in a single pass. MO disks, however, are considered more stable. Most disks will allow up to 1,000,000 rewrites compared to about 100,000 rewrites for a PCR disk. Currently MO technology is the predominate optical recording technology.

Although, optical recording technology can operate in very harsh environments, it lacks several performance parameters for reconnaissance systems specifically; data transfer rates. Typically optical recorders can only operate at rates in the general area of 10 Mbp. The primary advantage of optical memories for reconnaissance applications is that optical disks are easily removable, and it costs relatively little to produce a large number of permanent copies for image exploitation.

4.3.2 ASSESSMENT OF OPTICAL DISK RECORDING

The next logical step in the evolution of MO technology is to double the capacity of the current drives and media storage. The exciting aspect of this evolution is that it can be accomplished fairly easily with current technologies and methods.

One step to increase the storage capacity of optical disk systems is by implementing zone-bit recording (ZBR) or zone constant angular velocity (ZCAV). ZBR is a method in which more sectors are recorded at the outer radius of the disk to maximize bit density. This method has been used extensively in magnetic recording over the last three to four years. Another technique to increase storage capacity is pulse-width modulation (PWM) recording and pulse-position modulation (PPM). In PPM, the information (i.e., data) is contained in the time between the positive peaks of the read back signal. The positive peaks correspond to the center of the written domain. With PWM, the information is contained in the time between the transitions (edges) of the read back signals. The important parameters in PWM are the length of the domains and the time between the domains. In optical PWM recording, the big challenge is the precise control of the domain edges. Writing an MO disk is primarily a thermal process with the laser serving

as the heat source. Care must be taken to control the laser power accurately to write consistent, well-defined domains. The change to a PWM system alone will double disk capacity.

The final evolutionary changes to the MO system needed to increase capacity involves the optics of the drive. The bit density you can achieve on a disk is directly related to the spot size of the focused laser beam on the disk. The size of the spot is directly related to the laser wavelength and the numerical aperture (NA) of the objective lens, so by decreasing the laser wavelength and increasing the NA, the spot size—and therefore the bit size—can be significantly decreased. Current systems typically use a laser with a wavelength of 780 nanometers (nm) and an NA of 0.55. Future drives will incorporate 670 nm lasers and objective lenses with an NA approaching 0.60, which will allow a 12% reduction in spot size or a 30% potential increase in capacity.

Other techniques expected to be important are optical super-resolution which modifies the optical power distribution of the beam focused on the optical disk. Power is shifted away from the center of the beam toward the edges producing, through diffraction, a smaller focused spot. This smaller spot can resolve smaller features on the disk, allowing increased capacity without increases in NA or decreases in wavelength. It is projected that optical super-resolution may provide 20% to 30% in track density increases.

Magnetic super-resolution, or MSR, is an even more promising, super-resolving technique for MO optical disks. Rather than changing the optical power distribution in the focused laser beam, MSR produces a submicron-size aperture, or window, at the focused spot. The size of this window determines the resolution of the MO drive, rather than the size of the focused laser spot. While the focused laser spot may have a diameter

of 1 micron, this magnetic window can have a size of much less than a micron, on the order of 0.3 microns in size.

As these various methods evolve to provide greater recording densities, methods to reduce noise will need to be employed. Much of this technology, such as partial-response maximum-likelihood (PRML), inter-symbol interference (ISI) and others signal detection techniques, has already been applied to magnetic recording systems. In addition to the above evolving technologies, improvement in the MO media will further push the envelope for increased storage. Today's media research is focusing on four key areas:

- ☐ lower noise media for higher density,
- ☐ short wavelength-response MO materials,
- ☐ magnetic super-resolution constructions, and
- ☐ media that will allow single-pass direct overwrite of data.

Another area of improvement is placing several layers of media on a single disk substrate. In this configuration each layer is sensitive to a particular laser wavelength. Currently there is a demonstrable two layer optical disk with a five layer system under development. This development essentially combines different media on a single substrate and increases the storage capacity and input/output by the number of layers.

To fully exploit the advantages of the above, the Advanced Research Project Agency (ARPA) has selected the Air Force's Rome Laboratory to be ARPA's executive agent for the "Short-Wavelength Optical Storage" Technology Reinvestment Project (TRP). The primary goal of this project is to develop the technology needed to store 20 GB on a

5.25" optical disk by calendar year 2000. The equipment will also demonstrate access times and transfer rates that are at least equivalent to magnetic disk technology.

4.3.3 3-D OPTICAL RECORDING

The above optical storage approaches are one-dimensional in a two-dimensional space (even the multilayer media is still two-dimensional). A technology that is emerging from the laboratories is a 3-D optical recording concept which allows recording of information throughout a volume of media. Three-dimensional recording is a single memory unit where three independent coordinates are used to specify the location of information. It may be classified as either bit-plane recording or holographic recording. The bit plane recording generally records the amplitude of a focused laser beam while the holographic recording records the phase characteristics of a coherent laser beam. Both methods of 3-D recording currently have the capability to record one gigabit per second.

4.3.3.1 3-D Bit Plane

In a 3-D bit-oriented recording each bit occupies a specific location in 3-D space. This method differs significantly from 3-D holographic memories where the information associated with stored bits is distributed throughout the memory space. In bit-oriented 3-D memories, the coordinates which specify the location of the information can be spatial, spectral, or temporal thus giving rise to a variety of 3-D memory concepts that use different materials with various properties. Currently there are three different materials to bit plane recording: two-photo absorption recording using spiropyrans, bacteriorhodopsin, and rhodamine-b. Prototypes of this optical recording technology have demonstrated a storage capacity of 1 terabit per cubic centimeter. This volume

parameter only addresses the media and the volume required for the supporting components (laser, power, etc.) is more than a cubic centimeter but considerably less than any other aerial reconnaissance recording approach. In addition this technology is also pursuing a fourth dimension, where each location in 3-D space is recorded as a color pixel or change in molecular structure, to increase storage capacity.

4.3.3.2 3-D Holographic

Another type of 3-D emerging optical recording technique is holography. Holography has the potential to be more reliable than current recording approaches since the information is stored collectively throughout the recording medium and is not susceptible to loss due to dust, scratches, or other media handling problems. The recording medium for holographic storage is generally a solid volume of homogeneous material. Recently emergence of improved critical components such as laser diodes, spatial light modulators, and detector arrays can potentially overcome some of the limitations of previous system implementations.

4.3.4 ASSESSMENT OF 3-D RECORDING

Three-dimensional recording prototype systems have been fabricated and tested. This recording approach has all of the unique attributes of low power, small footprint, non-volatile, low cost, and high volume storage. The Air Force, Rome Laboratory, and commercial ventures are pursuing several different equipment approaches to developing first production models. The current assessment is that this 3-D technology is about five years away from becoming a viable commercial product.

5.0 ASSESSMENT AND DEVELOPMENT PLAN

This section describes the results of the analysis performed on the available and competing reconnaissance data recording technologies for use in the Advanced Tactical Air Reconnaissance System (ATARS) or any Tactical Reconnaissance System (TRS). The emphasis of this analysis was to investigate the application of the Sony DVR-2 Tape Recorder to meet U.S. commercial and military digital recording needs. Included was a study of the ability to modify this recorder's digital interface to be compatible with the full spectrum of ATARS electronic requirements.

5.1 COMMERCIAL RECORDING TECHNOLOGY

Commercial developments in the area of digital video recording have made available high-bandwidth, digitally-based Digital Video Tape Recorders (DVTRs) that can be purchased at relatively low cost when compared to conventional digital instrumentation recorders. The promise of better picture and sound quality for professional video recording was the original spur to the development of the DVTR, but in the early formats this high quality also came with a high price tag. However, due to recent tape recording density and VLSI chip advancements, DVTRs are now inexpensive and readily obtainable. This trend is expected to continue as the DVTR becomes the standard video

recorder, virtually eliminating the use of analog video recorders (much as the compact disc eliminated the vinyl record).

In the early phases of the Digital Image Verification System (DIVS) program, Computing Devices International (CDI) investigated the uses of a commercially available Sony DVR-2 digital tape recorder. This equipment is commonly used by video journalists and, as a consequence, may be subjected to considerable abuse during recording operation.

As part of this study effort, CDI looked into the possibility of modifying the Sony DVR-2 to allow for interfacing to standard digital data. We have determined that modification of the DVR-2 to enable it to record and playback standard data is feasible, but we have also identified some areas of risk that would be associated with the effort.

This section on commercial recording technology presents some background information and addresses some of the issues associated with leveraging the commercial video recorder industry. It also discusses the possible modification of a portable, low cost DVTR (the Sony DVR-2) to support use as a digital tape recorder for airborne reconnaissance data recording applications.

5.2 THE DIGITAL VIDEO TAPE RECORDER

The first production DVTRs were available in 1987 and used the D-1 format, which recorded color difference data according to CCIR-601 on 3/4" tape. The D-1 format was too early to take advantage of high-coercivity tapes and its recording density was quite low. Where applications existed, the D-1 format could not compete economically with

Betacam SP and M-II analog formats. As a result D-1 found application only in high-end post production areas of the professional video industry.

The D-2 format came next, using a composite digital format capable of handling conventional PAL and NTSC signals in digital form. D-2 uses the same 3/4" cassette shell as D-1, but the tape was replaced with a higher-coercivity 1600 Oe metal particle formulation that allowed for higher data densities and longer playing time. A further increase in data density was achieved by incorporating azimuth recording. The choice of composite recording allowed broadcasters to directly replace analog recorders with a digital machine.

The imminent arrival of the D-3 format will provide twice the recording density of D-2, and three times that of D-1. This will permit the use of 1/2" tape, making a digital camcorder possible. The D-3 format uses the same sampling structure as D-2 for its composite recording, but coming later, D-3 has learned from earlier formats and has a more powerful error correction strategy, particularly in audio recording. Another format being talked about is the D-5 format which would be backward compatible with the D-3 format, but will double the tape speed in order to increase the bit rate, providing even higher quality and better error correction.

Since today's readily available machines utilize the D-2 format, this discussion addresses the feasibility of modifying a D-2 format DVTR to be used as a general purpose data recorder for reconnaissance applications where a lightweight, portable recorder is desired.

5.3 SONY DVR-2 RECORDER MODIFICATION

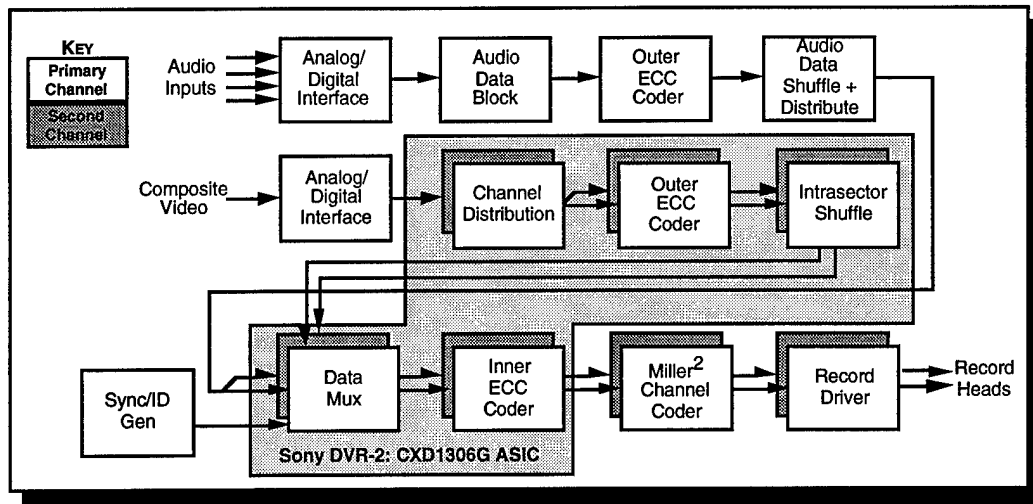
In analog video systems, the time axis is already sampled into frames and the vertical axis is sampled into lines. Digital video simply adds a third sampling process which takes place along the lines. The following sections will discuss how, when modifying a DVTR to record/playback digital data, the challenge presented is to provide and monitor for digital data in place of the true picture data during the correct time period within a composite video signal.

5.3.1 DESCRIPTION

The DVR-2 is a small digital tape recorder that occupies less than one cubic foot and has a tape that can hold over 500 gigabits of data on a standard 90-minute D-2 format video tape cassette. The DVR-2 video recorder interfaces to standard video signals, but is internally a digital recorder that contains analog to digital converters (ADCs) and digital to analog converters (DACs) to convert between the analog interface and the digital recorder.

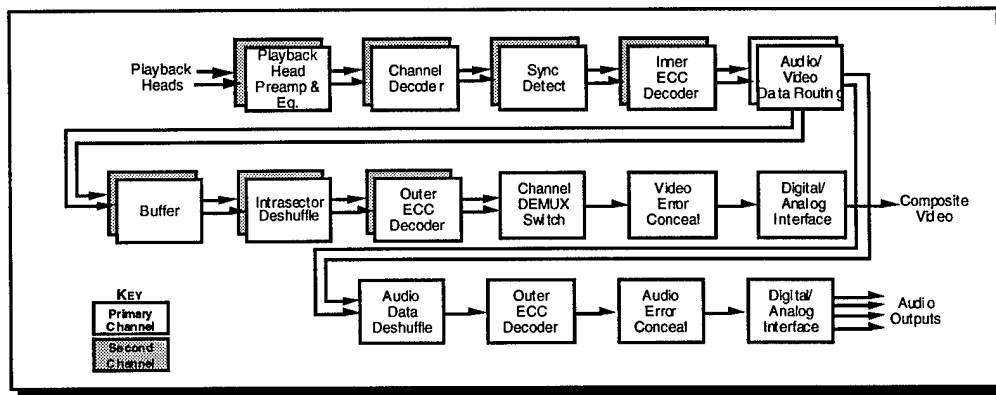
A recording operation flow diagram of the D-2 format is shown in Exhibit 4. After the analog video signal is converted to digital data, it is distributed into two logical channels, each channel containing half of the original number of samples in each line: 474 in PAL format and 384 in NTSC. Each channel is then sent through Error Correction Code (ECC) processing and data shuffling before sending it on to a data mux, where it is interleaved with audio data, sync data, and track ID information. It is then sent on for additional ECC coding, serializing, and Miller channel coding before finally being sent on to the record heads.

Exhibit 4 D-2 Format Record Flow



The playback operation flow diagram is shown in Exhibit 5 and is basically in reverse to the record flow. From the playback heads, the data go through channel decoding, sync detection, and ECC decoding before being separated into video and audio data streams. The video data are then buffered until enough data are accumulated to allow for deshuffling and additional ECC decoding. The two logical channels are then combined before being sent through video error concealment processing and finally being converted back to a composite analog video signal by the digital to analog converter.

Exhibit 5 D-2 Format Playback Flow



As these operation flow diagrams show, the video and audio data are interleaved along with sync and frame ID information when residing on the actual tape. Exhibit 4 also shows that, in the DVR-2, most of the interleaving function and video processing is done inside a single ASIC. This limits where digital data can be inserted in the processing stream to either directly before the Miller channel coding, or directly after the analog to digital conversion process. Since the data being sent from the CXD1306G ASIC to the Miller coding ASIC is serialized, two-channel data, interleaved with specific sync and track ID information, it really is not a viable option to insert the digital data at that location. Providing data in a compatible format would require a large design effort and quite a lot of circuitry. This leaves insertion of digital data directly after the ADC process as the only real alternative. At this point, the video signal is sampled into 8-bit digital data, which is the same data width that instrumentation recorders such as the Ampex DCRSi provides. This 8-bit data path provides a much easier digital format to which to interface.

However, inserting digital data after the analog process in place of the digitized video data requires that the data adhere to the PAL or NTSC composite video format. Only data provided during the true picture portion of the composite video (i.e., not the vertical or horizontal blanking intervals) will be processed through the rest of the digital circuitry and get written to the tape. This means that when providing data for recording, certain signals in the DVR-2 must be monitored for determining when to send data in place of the picture portion of the video signal. During playback, signals must be monitored to determine when valid data are available from the DVR-2.

Determining what signals to monitor, and how to design the interface based on those signals, is part of the challenge to modifying the Sony DVR-2 to enable it to be used as a

general-purpose data recorder. In the D-2 format, this valid data section amounts to 768 samples out of the 910 samples per horizontal video line using NTSC video, and 948 out of 1,135 (or in some lines 1,137) samples using PAL.

5.4 DVR-2 DEVELOPMENT PLAN

The DVR-2 has the potential of applying commercial technology to a military application; however there are some risks associated with modifying a commercial product. The following sections discuss the technical/engineering approach to modifying a DVR-2 of aerial reconnaissance recording, the risks associated with these modifications, and a program plan.

5.4.1 TECHNICAL APPROACH FOR DVR-2 MODIFICATION

As discussed in the previous section, modification of the Sony DVR-2 would basically consist of tapping into the digital portion of the recorder right at the ADC (recording) and DAC (playback). However, since the Sony DVR-2 (and for that matter, all DVTRs) is meant to be a higher quality alternative for recording a conventional video waveform, care must be taken to provide and monitor interface data during the correct time period of the standard video waveform.

On providing record data to the recorder, modification must consist of a gating signal that would let the external interface know when it is okay to send data, and when data cannot be accepted by the DVR-2. This gating signal would be provided by control logic that is

based on certain, yet to be determined, signals internal to the DVR-2. First-In First-Out (FIFO) storage devices would also have to be used to buffer the data until they can be properly sent to the DVR-2. These FIFOs can either be provided as part of the DVR-2 modification or a requirement can be placed on the external sending device to monitor an "okay-to-send" signal, and buffer the data itself. When sending data to the DVR-2, care would also have to be taken to allow for tape start and stop times. Note that internal FIFOs and allowing for start/stop times is part of where the higher cost of instrumentation recorders is incurred.

In order to record data, a video reference signal must also be provided to the DVR-2 so that it can generate its internal clocking signals. It is not clear, from the documentation we have, if this can be accomplished by modifying the DVR-2 itself or if an external composite video signal must be provided. Modification may therefore necessarily consist of a PAL or NTSC video waveform generator.

When recording data, the DVR-2 has no way of knowing and does not care when valid data are being provided. The recording process would have to consist of placing the recorder into "record" mode and then sending data. To assure that there are no gaps in the data when being played back, data must be consistently available whenever the DVR-2 wants them. The external interface must therefore be able to keep up with both the burst and average data rates of the DVR-2. These data rates required are discussed in more detail in the next two paragraphs.

The burst rate of the DVR-2 is the sampling frequency that is used internal to the DVR-2. This sampling frequency, and thus the burst data rate, is approximately 14.32 million bytes/second for NTSC video, and 17.72 million bytes/second for PAL video.

The average data rate of the modified DVR-2 that NTSC video would provide calculates out to $(1 \text{ byte/sample} * 768 \text{ samples/line} * 255 \text{ lines/half-frame} * 59.94 \text{ half-frames/second}) = 11.738 \text{ million bytes/second}$. The average data rate that PAL would provide calculates to $(1 \text{ byte/sample} * 948 \text{ samples/line} * 304 \text{ lines/half-frame} * 50 \text{ half-frames/second}) = 14.409 \text{ million bytes per second}$.

On receiving playback data from the recorder, another gating signal must be provided to let the external device know when valid data are being sent from the DVR-2. This gating signal again would be provided by control logic that is based on certain, yet to be determined, signals internal to the DVR-2. Also, FIFOs must again be used to buffer data if the external devices cannot keep up with the burst or average data rates of the DVR-2.

If the external device cannot keep up with the DVR-2, there is no way of telling the digital interface to stop sending data. The tape would therefore have to be stopped via the serial command interface (discussed later), rewound, and started again when the external interface is able to accept data.

Another issue that surfaced during this investigation was the way the D-2 format handles error concealment. If there are bad portions of the tape that are encountered when reading back data, the D-2 handles it differently depending on the extent of the data error. In the case of single bit errors and some multibit errors, the inner ECC decoder of the playback circuitry will correct the bit automatically. Thus, the external interface will never see these small errors and they are of no concern.

However, if the error is many bits that cannot be corrected by ECC, the errors are not corrected and the data shuffling function in the DVTR will spread these errors out over a larger area of data. Thus an error that occurs on the tape surface will be spread out over

an entire video frame of data. Data bytes that are in error will be estimated based on neighboring bytes and past data frame(s). Therefore, the user data format protocol must provide some sort of error detection of its own (most likely by check summing) that would detect and flag errors encountered in critical data.

The DVR-2 shuffles data and provides lost data estimation in order to provide a better quality picture. Tape errors are spread out over a frame of data and filled in by estimation, thus nearly eliminating the problem of localized data fallout seen using standard analog video recorders. In the case of trying to use the DVR-2 as a general purpose recorder, the effect is spreading out localized tape errors over a larger section of data, and therefore affecting a larger number of data packets.

Providing a serial (RS-232) interface is necessary to provide remote operation (not manual push-button). A remote control that plugs into a serial interface of the DVR-2 is available, so therefore a serial interface is provided. However, none of the documentation we have describes the protocol of this interface. This is information that we have not been able to obtain from Sony. Identifying the operation of this serial interface will be required.

Being capable of withstanding harsh environments is another item that must be considered. Whether or not the modified recorder is compatible with all of the reconnaissance data recording environmental and operational needs really depends on the platform. For purposes of this report, the Sony DVR-2 is a commercial recorder, but has also been designed to be somewhat rugged based on being a portable unit.

5.4.2 RISKS ASSOCIATED WITH DVR-2 MODIFICATIONS

In looking at the possibility of modifying the DVR-2, several risk items have been identified that would be affected by any modification effort. These risk items are listed here.

- ❑ Minimal documentation on the ASICs in the DVR-2: Sony has verbally stated that they do not have any other information than what is contained in the maintenance manuals. Any specifications for the many ASICs in the DVR-2 cannot be obtained, even by United States Sony engineers (the product was designed in Japan).
- ❑ Minimal technical assistance from Sony: Sony has verbally stated that they will not provide any direct assistance in modifying the DVR-2. They would be available to answer quick and simple questions, but really want no involvement.
- ❑ Sony experts feel this is not an easy task: The Sony D-2 product line manager and the Sony D-2 principal product engineer have both verbally stated that the effort is feasible, but not an easy task.
- ❑ Any modification voids Sony warranty: Any modification of the Sony DVR-2 would void the warranty. If in the design or modification one of the Sony components fails, it may be difficult getting it repaired or replaced.
- ❑ Finding proper signals to provide gating signals: Because of the minimal documentation, the only way to find the appropriate signals to be used for providing the gating signals would be to probe the DVR-2 circuit boards. It appears that there are several candidate signals available, but most of the

recording circuitry is contained inside a single ASIC. Proper timing signals external to the ASIC will be required.

- ❑ Protocol of the serial interface: Getting documentation on the protocol of the serial interface may not be possible. If it is not available, then other experimental methods of determining its operation may need to be used.
- ❑ Noise considerations: When interfacing to devices that operate at the clock rates internal to the DVR-2, additional care must be taken to assure noise tolerances are accounted for. Lack of documentation makes this effort more difficult.
- ❑ Power requirements: The digital interface to the DVR-2 would most likely consist of ECL signals. These devices draw a moderate amount of power and care will have to be taken not overload or overheat other parts of the DVR-2.
- ❑ Interface drive characteristics: Since we cannot get any additional documentation on the ASICs, we will not be able to analyze our interface design to keep within the drive/receive capabilities of the DVR-2 components. This may make for some trial and error design methods.
- ❑ Space limitations: Keeping the design small enough to fit into the space available inside the DVR-2 will be a challenge itself. There is little space available, so any modifications must contain minimal circuitry and small components.

5.4.3 DVR-2 PROGRAM PLAN

After performing an engineering analysis of the modifications required for the DVR-2 to support an aerial reconnaissance recording capability, this analysis has determined that this would indeed be a feasible project. However, based on the risks that have been identified, the effort would not be as straightforward and simple as perhaps first envisioned. Great care will need to be taken to not harm components of the DVR-2 and to provide a clean interface design. Any effort to modify the DVR-2 should consist of two distinct phases.

PHASE I Phase I would explore the operation of the DVR-2 and identify what timing signals are available and exactly where to interface to them. This would effectively be an initial design study to help minimize the risk items and determine exactly what would be involved in a modification effort. It may also find that some of the possible risk items are too great to overcome and the modification of the DVR-2 is not a feasible effort after all. This could be accomplished with an approximate two to three man-month effort. It is recommended that this phase be done before estimating the size of the modification effort itself.

PHASE II Phase II would design and implement the modifications and define the interface requirements, to be done only after the risk items have been minimized. The design would then be checked out and interfaced to an external device. This phase would only be done after successful completion of Phase I.

6.0 S/TODS ASSESSMENT

6.1 INTRODUCTION

The Air Force's Rome Laboratory Intelligence and Reconnaissance Directorate has a technology program in Intelligence. Under that technology program Rome Laboratory has developed optical disk recording systems for aircraft environments. Three advanced development models were built and tested:

- The Tactical Optical Disk System (TODS) is a 5.24" diameter, rewritable optical disk system designed to operate on a tactical fighter aircraft. This system was designed to function within high and low temperature ranges, vibration, mechanical shock, acceleration, and the altitude and humidity of a tactical fighter aircraft. This system had the following performance parameters:

- ◆ Storage Capacity: 300 megabytes, single side
- ◆ Data Transfer Rates: 5 megabits per second, sustained
- ◆ 10 megabits per second, burst
- ◆ Maximum access time: 100 milliseconds (inner to outer radius)
- ◆ Size: 5" x 6.5" x 10.5"
- ◆ Weight: 16 pounds with disk cartridge

- The Strategic/Tactical Optical Disk System (S/TODS) is a 14" rewritable optical disk system and provides a greater capacity than the 5.24" system. S/TODS is capable of functioning in the same operational environment of a

tactical fighter aircraft. This system had the following performance parameters:

- ◆ Storage Capacity: 6 gigabytes, single side
 - ◆ Data Transfer Rates: 25 megabits per second, sustained
 - ◆ 50 megabits per second, burst
 - ◆ Maximum access time : 400 milliseconds (inner to outer radius)
 - ◆ Size: 17.5" x 23" x 24"
- ❑ Weight: 150 pounds with disk cartridge
- ❑ A deployable optical jukebox designed to be operated in a fixed facility environment. This system has 10 double-sided rewritable optical disks capable of storing 120 gigabytes. This system cannot be operated in an aircraft.

The TODS and S/TODS were tested in an operational air craft environment by Rome Laboratory and all performance parameters were met. The deployable jukebox has been tested and is scheduled to be deployed to the American Air Command in May 1996.

6.2 ASSESSMENT

The TODS and S/TODS developments demonstrated the value of using an optical disk recording capability in an aircraft environment. However, based upon the significant and relatively rapid improvements in read and write components, and the improvements in

media that were discussed in Section 4, the current Air Force program is oriented towards using standard commercial components as the basis for any future aircraft recording requirements. Future Air Force optical disks systems will use commercial optical disk components mounted in an enclosure for aircraft operation, and use rugged electronic components for system input and output, and optical disk component control.

6.3 S/TODS DEVELOPMENT PLAN

The Air Force S/TODS advanced development programs have demonstrated that an optical disk system can be cost effectively used in an aircraft environment, but an S/TODS did not meet the requirements for a reconnaissance recording system. For an S/TODS to meet these requirements, an optical disk system would have to be configured as a Redundant Array of Inexpensive Devices (RAID) system. Since the S/TODS development will be using commercial optical disk components, an S/TODS development to meet the requirements for a reconnaissance recording system should also use the same development concept. Therefore a development program building upon the investments in S/TODS would be based upon using commercial optical disk components in a RAID configuration, with an electronic solid state buffer to manage the burst recording requirements. To be able to appropriately manage these two recording systems, a media management system should be considered.

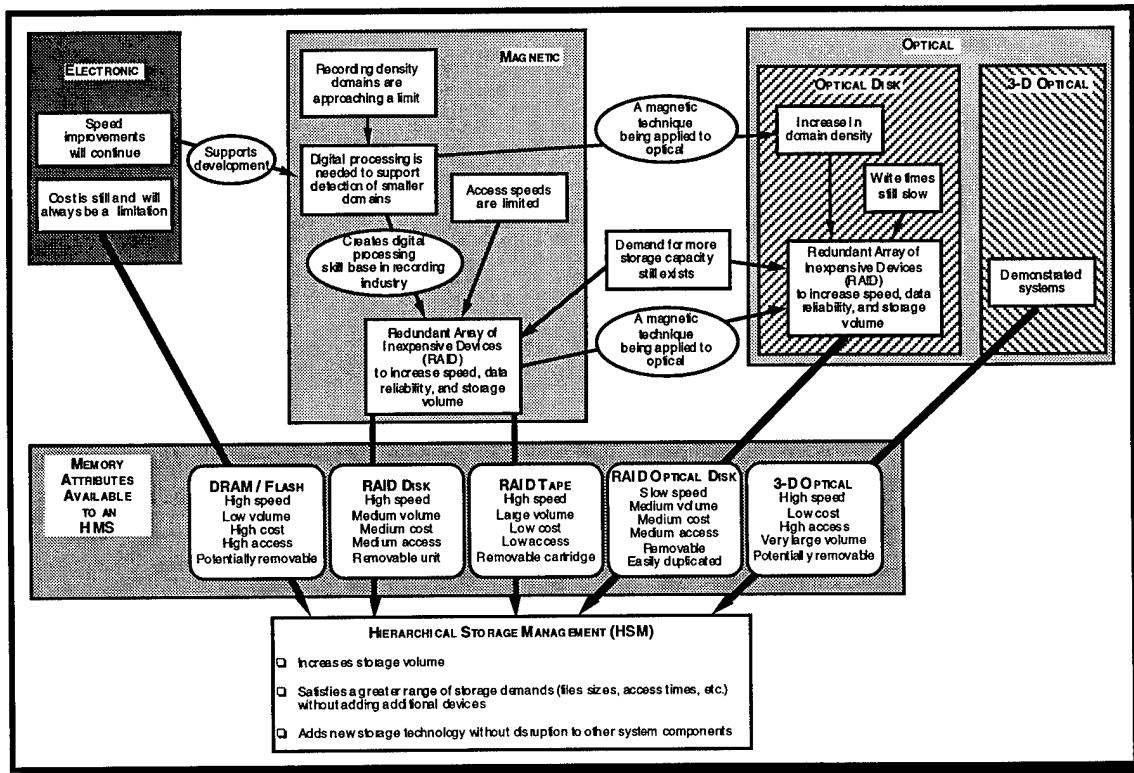
Once a media management system is considered it only make sense that a more robust Hierarchical Storage Management(HSM) should be employed. An HSM supporting an optical disk system would allow incorporation of new optical technology as it evolves, without changing other portions of the recording system and interfaces to the recording

system. Therefore an S/TODS development program should follow the Reconnaissance Data Recording Road Map and Development Plan.

7.0 DOWN SELECTION OF RECORDING TECHNOLOGIES

The down selection of recording technologies was conducted as illustrated in Exhibit 6. The results of the assessment of the DVR-2 and the S/TODS were also used in their appropriate recording categories.

Exhibit 6 Down Selection

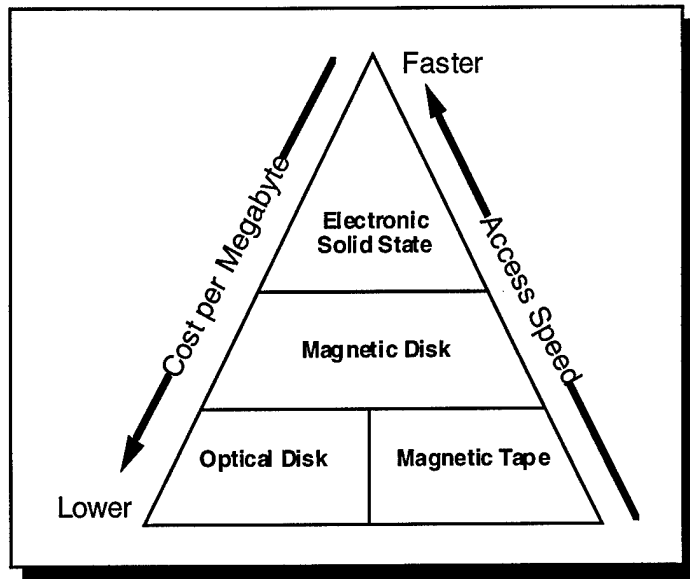


Electronic data processing technology is a critical technology that cuts across all of the recording technologies. This technology is becoming increasingly supportive of magnetic and optical recording technologies. As noted in the assessment of each of these technologies, the media controller has evolved to become a data processing system for media control and signal processing/detection of smaller and smaller recording domains. The increased emphasis in applying data processing capabilities in magnetic and optical recording technology also fostered the evolution of the RAID. Concurrent with the expansion of RAID it became obvious that it is possible to go beyond an array of identical devices and have an array of different devices. As the diversity of devices expanded it became necessary to implement a management system. Since the diversity of devices was getting wider and wider the only solution that could accommodate all possible combinations of media types was the HSM. There is no single recording technology that is currently under development that can accommodate all of the recording requirements for a reconnaissance system. Each recording technology has its own set of attributes.

7.1 RECORDING TECHNOLOGY ATTRIBUTES

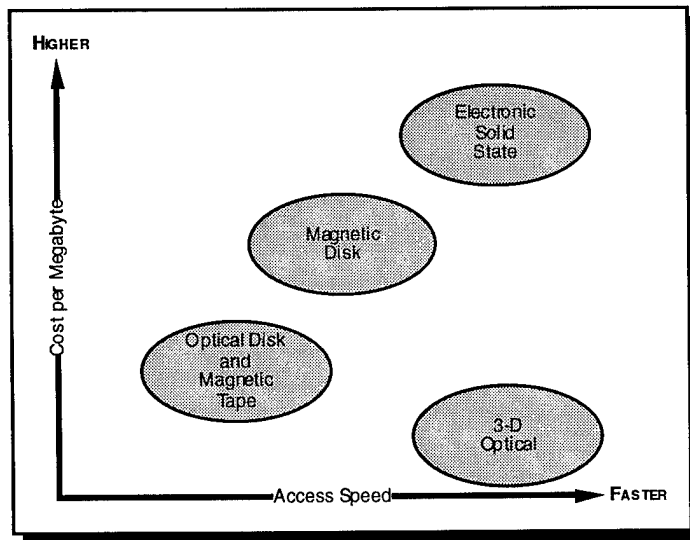
The combination of access time and capacity attributes is frequently used to catalog or define a storage hierarchy "pyramid", as illustrated in Exhibit 7. This shows the fastest, most expensive memory type at the top of the pyramid, followed by the slower and less expensive, but more capacious memories, below. This type of diagram is frequently shown but suffers from oversimplification. At the present time, magnetic hard disks are both faster and less expensive per megabyte than magneto-optical disks. Magneto-optical disks and tape systems are most practical when used with large volumes of removable media, such as in a possible reconnaissance collection system.

Exhibit 7 Memory Hierarchy Pyramid



The 3-D optical capabilities are not included in the above exhibit. Exhibit 8 places the access and cost of 3-D optical memory in perspective with the more traditional recording capabilities.

Exhibit 8 Recording Capabilities as a Function of Cost vs. Access



The potential cost of 3-D optical recording systems will be significantly below the current traditional recording technologies, and because 3-D systems have parallel input and output capabilities, the access can be as fast as the electronic solid state recording systems.

To overcome the access limitations, developers of the traditional recording technologies are now using high speed digital processing devices to control multiple recording units. These high speed digital processing approaches were initially incorporated to provide high speed access to the media via multiple channels, and to improved capability to detect weaker and smaller recording domains. During these developments it became obvious that with a limited expansion of the digital processing capability, multiple media devices could be served simultaneously. Once multiple independent devices were placed under the control of a single digit processing unity, multiple methods of recording data and different approaches to data survivability were implemented. This development is referred to as RAID (Redundant Array of Independent Devices), and now a wider family of inexpensive, large capacity, small footprint, and very robust recording systems have been produced.

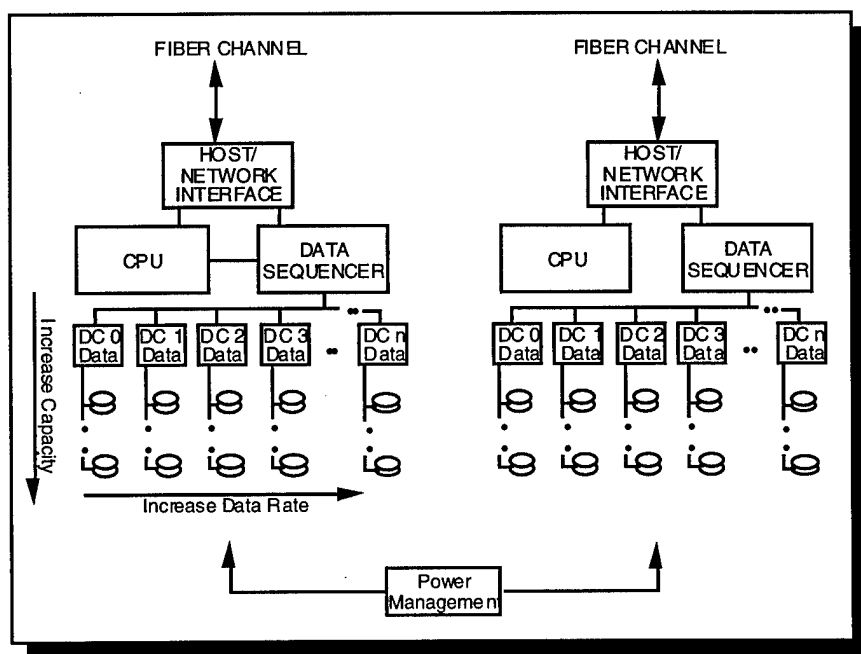
7.1.1 REDUNDANT ARRAY OF INDEPENDENT DEVICES

The continuing rapid evolution in disk drive technology, and growth in disk capacity, make the disk array attractive for aerial reconnaissance recording applications. The RAID approach can be adapted to accommodate a variety of data rates and storage capacities. An array of drives also offers an opportunity to provide redundancy against most all single point failures. The number of disk drives within a RAID system can vary

from a few to hundreds depending on the system requirements. In the case of the reconnaissance recording system the number of drives required would be in the range of two to ten, depending upon the system/sensor requirements.

The example shown in Exhibit 9 depicts a RAID configuration with array of disk drives. The fiber channel supports data rates from the host at up to 100 Mbytes/sec. The width of the disk array can be configured to accommodate the required data rates, while the depth of the array can be configured to accommodate the required data capacity. Data parity can be added for increased protection of data integrity. With the addition of cross-connection of data and a power management function, protection against single-point failures can be added.

Exhibit 9 Typical RAID Configurations



When there is a need to transmit specific segments of a reconnaissance mission's data, perhaps as the result of some important event that occurred during the mission, and it is

urgent that the data be analyzed, random access of disks has a distinct advantage over the current magnetic tape systems under development for reconnaissance systems.

Following are summary specifications for a RAID configuration with the fiber channel interface.

- ◆ Data Rate: Up to 100 Mbytes/sec (800 Mbits/sec)
- ◆ Capacity: Up to 72 Gbytes (eight 9-Gbyte Data Drives + Parity Drive)
- ◆ Size: 5.0 " H x 9.0" W x 18.0" D
- ◆ Weight: 35 lb.
- ◆ Power: 120 watts

Media bit density capabilities (both optical and magnetic) are growing at an incredibly fast rate, and therefore disk storage capacities are increasing without an increase in physical size. Advances in RAID controllers, data interfaces, and data compression techniques are allowing unimaginable data transfer rates. With these immense technological changes sponsored by commercial interest comes the challenge of using this capability for military reconnaissance recording applications

However these changes are now forcing developers to include a data processing function to manage data across several devices. There is an old storage technique that is adding RAID function to the task of managing different types of storage media. This storage technique is Hierarchical Storage Management (HSM). Although HSM technology has been used on main frame systems for probably 20 years, its applications to mid range, PC-LAN, and PCs is relatively new, with the first commercially available packages introduced in 1992 and 1993. Current commercial applications of HSM software support high capacity autoloaders and jukeboxes to move infrequently used files to cheaper,

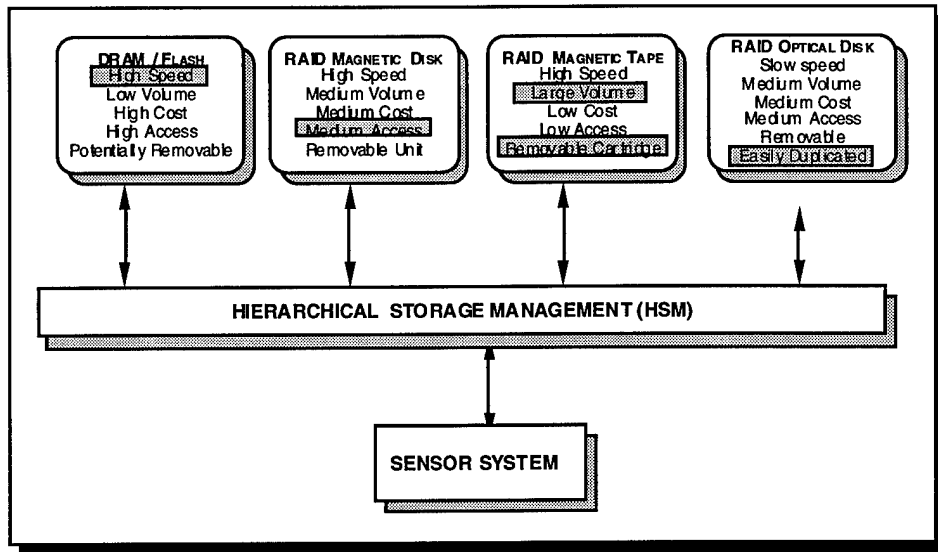
slower media, say, from on-line magnetic media to near-line optical or off-line tape media. However this same capability can be used in a reconnaissance recording application to support a very high speed burst of data on relatively low speed, large volume media.

7.1.2 HIERARCHICAL STORAGE MANAGEMENT

The major benefit desired to be achieved by use of an HSM in reconnaissance recording system is to isolate the sensor suite from the specific behavior of the recording media used to record the sensor data. Thus for example, a very high data rate burst from a SAR sensor or framing camera could be staged in a local high speed memory (RAM or disk), and then streamed out to a higher density tape media. This allows performance of the two storage media to be optimized for the specific function that must be performed, buffering or permanent storage. It is not necessary to find one memory that can do both well. The HSM transparently moves the acquired data back and forth between the available media depending upon the need for it. Further study is needed to determine if there is a synergistic combination of storage media that can be paired with an HSM which does not require an increase in the present size, weight, or volume of a comparable single media recording system.

Exhibit 10 illustrates an HSM system that is configured to use the best of all types of recording media. This configuration can be implemented to meet the requirements of the reconnaissance recording system that were used in this study.

Exhibit 10 Optimum HSM for a Reconnaissance System



8.0 RECONNAISSANCE DATA RECORDING ROAD MAP

8.1 INTRODUCTION

The results of this study indicate that additional development of the DVR-2 and the S/TODS cannot keep pace with the commercial recording developments. Therefore, in order to have a reconnaissance data recording program that can keep pace with technology and support a variety of recording demands, the best solution is to investigate the practical applications of an Hierarchical Storage Management (HSM) as the interfacing function between a sensor system and a recording system. This standard interfacing function has three major and significant benefits:

- ❑ Sensor system evolution. An HSM solution will allow the sensor systems to evolve and will not have a severe rippling effect on the recording system when new and different sensor are used, specifically:
 - ◆ Sensor formats can change both in format, size, and speed.
 - ◆ Different combinations of sensors can be used.

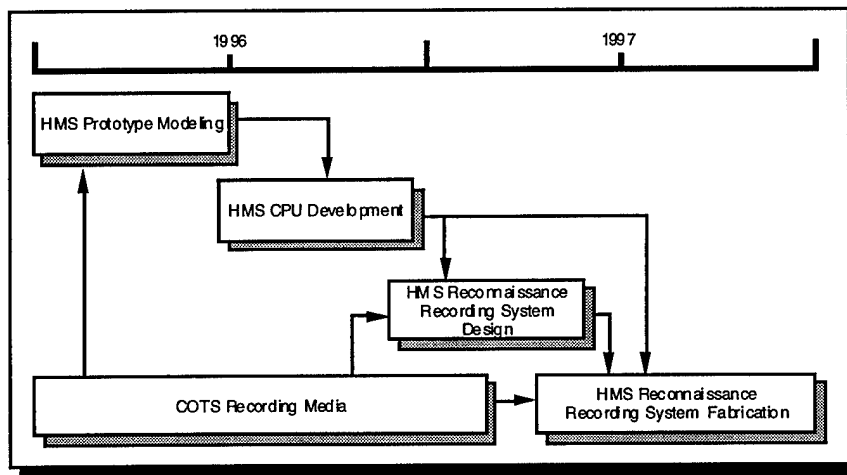
- ❑ Recording System Configuration. An HSM solution will allow different weight, size, and footprint configurations to be used.
 - ◆ Different methods of data transports can be used. Optical disk, magnetic tape, and other methods of data transport can be employed without major recording system modifications.
 - ◆ Different physical configurations. The recording media can be distributed throughout the air vehicle. There is no single footprint constraint for the recording system. Communication connections such as fiber optical may be necessary to connect the distributed recording media.
 - ◆ Different types of media can be used to meet the specific reconnaissance recording requirement. Such options include adding Flash memories to meet any unique sensor high speed recording demand, or adding RAID optical disks to provide a faster capability in data duplications. There is an endless number of performance trade-offs that can be made.

- ❑ Recording Media Evolution. An HSM solution will allow the recording media to evolve and take advantage of the tremendous and consistent commercial demand for better recording systems. Therefore it is in the best interest of a military reconnaissance development program to take full advantage of this commercially driven evolution.

8.2 ROAD MAP FOR RECONNAISSANCE DATA RECORDING SYSTEM

Exhibit 10 illustrates the road map for the development of an Hierarchical Storage Management (HSM) that will meet the needs of a reconnaissance recording system.

Exhibit 11 Road Map For Reconnaissance Data Recording System



The objective of this road map is to investigate the critical components that are necessary for an HSM Reconnaissance Recording System can cost effectively employ commercial off-the-shelf (COTS) recording media. Any limited quantity recording system (quantities less than 100,000) should use commercially developed media to reduce costs and development risk. The technology required to development special media and recording techniques is currently cost prohibitive and cannot compete with the investments that are being made for commercial recording systems.

8.2.1 HIERARCHICAL STORAGE MANAGEMENT PROTOTYPE MODELING

The first step would be to initiate a modeling effort to select an HSM and the media required to support a reconnaissance data collection requirement. This effort would evaluate various HSM approaches and COTS media component performance using a realistic set of parameters for sensor formats and data rates. This model would be used to evaluate all of the system requirements, including multiple ranges of access times for electronic transmission of data during the collection, to ensure that the system is responsive to a typical reconnaissance system.

The performance parameters of COTS media would be used in the modeling effort. Only those media that can already be cost effectively modified to operate in an aircraft environment would be considered. The results of this modeling effort would be used for:

- ☐ establishing the requirements for the development of a Computer Processing Unit (CPU) that has the data processing power to support the needs of a reconnaissance data recording system.
- ☐ establishing the parameters of an HSM Reconnaissance Recording System design effort.

8.2.2 HIERARCHICAL STORAGE MANAGEMENT COMPUTER PROCESSING UNIT DEVELOPMENT

The critical component for an HSM is the computer or data processing system within which the HSM operates. This CPU must be compatible with the sensor system and

capable of operating in an aircraft environment. There are several technical approaches that can be pursued to solve this environmental problem. One approach is to modify the existing reconnaissance data management system. Another is to investigate the application of clustered Digital Signal Processors (DSP) or other general processing solutions that have been designed to operate in an aircraft environment. A third alternative is to modify an existing CPU to be compatible with the reconnaissance systems and aircraft environment.

8.2.3 HIERARCHICAL STORAGE MANAGEMENT RECONNAISSANCE SYSTEM DESIGN

As soon as a technical approach for the HSM CPU has been selected, an HSM Reconnaissance Recording System can be initiated. The COTS recording media used in the modeling effort would be reviewed and those requiring modification would be evaluated for more definitive modification costs. This may include some actual modification and testing prior to committing to a system implementation.

The critical parameters of volume, weight, and power would be carefully assessed. As noted in the down selection discussion, an HSM has the unique property of distributing the recording system components so as to take maximum advantage of available space. Building upon the unique features of an HSM approach, the design would include installations in multiple aircraft environments, ranging from the more stable reconnaissance aircraft to the very dynamic reconnaissance unmanned aerial vehicles (UAV) systems. The results of this design effort would provide the appropriate information for fabrication the first HSM Reconnaissance Recording System.

8.2.4 HIERARCHICAL STORAGE MANAGEMENT RECONNAISSANCE RECORDING SYSTEM FABRICATION

This effort would use the results of the design effort and fabricate a prototype system. This fabrication effort would focus on the modular aspects so that this first system could be tested in multiple aircraft configurations supporting different reconnaissance sensor systems.

9.0 RECONNAISSANCE DATA RECORDING PLAN DEVELOPMENT

The Reconnaissance Data Recording Road Map establishes a set of activities leading to the development of an HSM Reconnaissance Recording System. The first step in that road map is the HSM prototype modeling effort. The following are the requirements for that development.

9.1 OBJECTIVE

The objective of this development is to analyze the application of an HSM system to support the recording requirement for a reconnaissance data recording system. The major emphasis of this effort is to select a combination of recording technologies that meet these requirements and minimize the operation requirements of space volume and power. A second emphasis shall be the selection of a data processing or computer processing unit

(CPU) that has compatibility with other data processing components of an aerial reconnaissance system.

9.2 BACKGROUND

Imaging reconnaissance must record very large volumes of data at a variety of data rates, in a serial manner, using a recording system that must consume low power and space, and have features that allow it to operate in a high performance aircraft. To date no single recording media has been able to meet these requirements. With the continuing increase in recording technology the only practical approach to the development of a reconnaissance recording system is to exploit the capabilities of an HSM. An HSM allows the upgrade of a recording technology without disrupting other components using the recording system. Additionally, as the recording requirements change, an HSM can be changed to meet those requirements without a major development activity. Changes to an HSM can be accomplished in weeks to months (discounting the time to make appropriate recording device changes to meet operational requirements), instead of months to years for the development of a new system.

9.3 TECHNICAL APPROACH

The technical approach to solving the sensor data recording problem is to use an HSM tailored to meet the performance requirements of imaging reconnaissance systems (including synthetic aperture). HSM has the unique feature of isolating a Reconnaissance

Management System (RMS) from the recording system. This feature permits a variety of media to be incorporated into a single recording system and allows a recording system to be modified without affecting the RMS so that different media types can be used to:

- ☐ support different mission and aircraft requirements, and
- ☐ accommodate new media system technology.

The technical approach to be pursued shall be to perform the following tasks:

- ☐ **TASK 1, SYSTEM REQUIREMENTS.** Define the requirements for an aircraft reconnaissance sensor data recording system.
- ☐ **TASK 2, SENSOR PROFILE.** Develop several sensor data profiles consisting of data rate and file sizes as a function of time.
- ☐ **TASK 3, HSM SURVEY.** Conduct a survey of commercially available HSM systems and perform a cost and performance analysis.
- ☐ **TASK 4, MEDIA CAPABILITY.** Collect performance and capabilities for all practical types of media that can be employed.
- ☐ **TASK 5, MEDIA OPTIONS.** Develop a number of media performance matrices. Each matrix shall consist of rows of media, with columns of performance requirements. These matrices shall be manipulated so that there are configurations of media (rows of two or more different media) where a column entry or sum (a system requirement) meets or exceeds the total requirement.

- ❑ **TASK 6, SYSTEM MODELING.** A recording system model shall be implemented using media configurations derived from the above matrices. Each model using the performance parameters (HSM and media configuration) shall be tested to determine the total recording system's performance using the sensor profile data developed under Task 1. The results of this task shall identify the following.
- ◆ HSM processor. An HSM processor shall be selected that can support a reconnaissance recording system and function in the operational environment of a tactical aircraft. Specifications shall be developed that can be used to design an HSM processor.
 - ◆ Recording media. A family of recording media shall be selected to meet a range of reconnaissance recording requirements. This family of media shall consist of, but not limited to, the following: magnetic tape, optical disk, solid state, and 3-D optical.

APPENDIX A — COTS RECORDING TECHNOLOGIES

INTRODUCTION

This appendix contains additional technical information that was used during the investigation into technologies that have application to reconnaissance data recording. It provides a quantization of the key performance attributes of current COTS mass memory technology and a projection of those attributes into the near future. The technologies of solid state (DRAM and Flash) and magneto optical are included for comparison purposes. Again, the main focus of this paper is magnetic tape and magnetic disk drives.

PERFORMANCE CHARACTERISTICS

Table 1 shows the key performance characteristics of the COTS memory technologies. The sections below provide a description of each of these performance characteristics.

Table 1 Representative Performance Characteristics of Commercial Memory Technologies

Tech- nology	Random Access Time (avg.) 512 Bytes	Native Media Transfer Rate (read/write)	Native On-line Capacity of Basic Device	Non- Vol- atile ?	Rewrit- ability	OEM Cost \$/MB Drive/ Media	Cubic Inches/ GB	Comment
DRAM	56.32 us	16 MB/s	.002 GB	no	Infinite	24	10.6	TI TMS 416400- 60
FLASH EPROM NAND	51 us read .6 ms write	9.6 MB/s read 727 kB/s write 18 MB/s read	.002 GB	yes	1,000,00 0	28	14	Toshiba TC5816F T

Tech- nology	Random Access Time (avg.) 512 Bytes	Native Media Transfer Rate (read/write)	Native On-line Capacity of Basic Device	Non- Vol- atile ?	Rewrit- ability	OEM Cost \$/MB Drive/ Media	Cubic Inches/ GB	Comment
NOR	70 ns read 1.25ms write	213 kB/s write)			1,000,000	24.4	17.2	Intel 28F016S
5.25" MO	29 ms	1.56 MB/s read 0.77 MB/s write	0.654 GB/side	yes	>1e7 cycles	1.46/.08 8	115.4	IBM 0632- CHA, half- high
3.5" MO	40 ms	1.1 MB/s read 0.55 MB/s write	0.230 GB/side	yes	>1e7 cycles	3.86 /.016	207.9	IBM MTA- 3230, 1" high
5.25" Mag	11 ms	5.5 - 8.125 MB/s	9 GB	yes	infinite	< 0.3	18.0	Seagate ST410800
3.5" Mag	8.5 ms	10.2 - 14.2 MB/s	8.7 GB	yes	infinite	< 0.3	4.3	IBM Ultrastar 2
1.8" Mag	17.7 ms	4.2 - 5.9 MB/s	421 MB	yes	infinite	1	6.97	Integral Cobalt 420
QIC Tape	43 sec	0.2 - 0.6 MB/s	2.5 GB	yes	limited by tape wear	0.4 / 0.017	33.7	Tandberg TDC4220
8 mm tape	13 sec	0.5 MB/s	5 GB	yes	limited by tape wear	1.14/.00 04		Exabyte EXB- 8505XL
4 mm tapes	?	0.5 MB/s	4 GB	yes	limited by tape wear	0.42 / .004	10.9	HP JetStore 6000
19mm tape	96 sec	13.375 MB/s	48 GB	yes	limited by tape wear	4.12/?	90.7	Ampex DCRSi 107r

RANDOM ACCESS TIME

Random Access Time is defined as the time to retrieve or write any given block of data starting from any other arbitrary location.

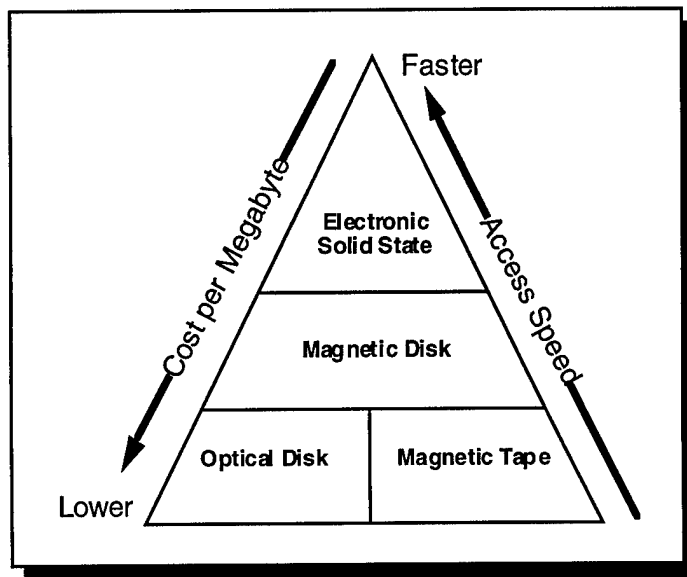
For DRAM memory the time shown is t_{RAC} , the access time from the row access strobe. Subsequent linear memory accesses can be performed with a shorter access time. No allowance was made for external decoding of addresses or other control signals. For Flash memory, the time shown for reading is the time to transfer the op-code to the chip, and transfer 512 bytes of data. In the case of writes, no erase time is assumed and time for a read verify is allowed.

Rotating disk memories of all types normally specify access time to be the combination of times required to perform a series of steps—decode the command to perform the requested memory access, move the actuator mechanism from its current radial position to the desired radial position, wait for the desired data block to rotate under the heads, transfer the data from the media to the host, and issue a “status” message. The dominant elements in this time are the times to move the actuator mechanism (perform a “seek”) and the time spent waiting for the desired data to appear under the head (latency). The statistical average of all possible seeks is a seek whose length covers one-third of the total number of all tracks. (Note that this time is longer than the deceptive specification of one-third of the time required to seek across all tracks.) The average latency is one-half of the rotational period of the disk.

Access time for tape systems is dominated by the time to move linearly past a large length of tape to access the desired section. This time is not typically specified for tape systems. The limitations on the speed of the mechanism, the speed of the tape itself, and head wearout must be balanced in order to determine if it is possible to move to a new tape region in a “fast forward” mode or in a search mode. We have used a typical search speed of 20X the play speed, covering one-third the total tape distance as an approximation of the access time

The combination of access time and capacity are frequently used to define a storage hierarchy “pyramid”, Exhibit 1. This shows the fastest, most expensive memory type at the top of the pyramid, followed by the slower and less expensive, but more capacious memories below. This type of diagram is frequently shown but suffers from oversimplification. At the present time, magnetic hard disks are both faster and less expensive per megabyte than magneto-optical disks. Magneto-optical disks and tape systems are most practical when used with large volumes of removable media, such as in a jukebox. In such an application the total capacity and total cost per megabyte will be as shown in Exhibit 1.

Exhibit 1 Memory Hierarchy Pyramid



Improvements in access times for all of these memory types has been modest over time. In the case of disks and tape this is due to both the mechanical nature of these mechanisms as well as to some interrelated electrical issues. The mechanical problems are fairly easy to understand. To move something faster you need more power and will probably make more noise. It is not desirable to increase either of these features. In the

case of disk drives, improved motors and bearings have allowed an increase of the normal spindle speed from 3,600 RPM (with 20 microinches of non-repeatable runout (NRRO) and an MTBF of 40,000 hours) in 1986 ,to 5,400 to 7,200 RPM in 1995 (with less than 6 microinches of NRRO and MTBFs of greater than 500,000 hours). Improved spindles, perhaps using fluidic bearings instead of ball bearings are expected to permit the use of 10,000 to 12,000 RPM spindles in 1996. A 12,000 RPM motor will permit, other things being equal, a reduction in average access time to the neighborhood of 6.8 ms (from 8.8 ms now) for a high performance disk drive.

Less obvious, but very important, is the impact upon the data signal processing requirements with an increase in spindle speed. Other than CD-ROM drives, all modern disk drives spin the disks at a constant angular velocity, causing the physical length of the region swept under the magnetic head or optical pickup (in any fixed time period) to be larger at larger radii. If the data were recorded by a fixed frequency clock, then the bits would occupy longer regions at the outside than at the inside radius. This fixed frequency recording method is very inefficient because it does not make full use of the maximum possible recording density except at the innermost radius.

Modern magneto-optical and magnetic disk drives record their data at nearly constant linear density. This is accomplished by dividing the surface of each disk into concentric bands, each band containing many tracks. The clock frequency used to record and read data in a given band is adjusted to make the linear density in each band near the maximum that the disk drive can support.

Increasing the spindle speed while maintaining the linear density of bits recorded on the media causes the rate at which the data is read or recorded to also increase (the same amount of data is seen in a smaller amount of time). Electronics suitable for cost

effectively processing the signals currently generated in disk drives are only slowly increasing their high frequency limits. This is one of the sources of the great pressure to go to smaller diameter media in magnetic hard disk drives. Decreasing the diameter of the disk permits increasing the linear density of recorded data, and/or the rotational rate, without proportionately increasing the fundamental frequency content of the data. In the case of magneto-optical disks, there is also a need to deliver a sufficient amount of power to the media in order to adequately heat it and permit its magnetization to be changed. At higher linear velocities the effective dwell time is reduced, requiring more source optical power.

MEDIA TRANSFER RATE

Arrays of the basic devices described here are natural to consider as a means of increasing the total storage capacity, and more importantly the data transfer rates.

For Flash memory, the write rate is substantially lower than the read rate. The times shown allow for the time needed to perform an erase before writing into a previously used region as well as a read to verify that the write executed correctly. Skillful system design can mask much of this difference for writes of modest size. One technique which can be used to do this is to provide a substantial amount of Flash memory beyond what the user can use. This added area can be used as a swap space, holding user data while a background erase is being performed in other memory areas. This type of activity, along with work needed to perform wear leveling, fault detection, validation after writing, etc., can reduce the user data rates to below the values expected from chip device specification sheets.

Magnetic hard disks have transfer rates from their media which varies as a function of zone and position within a zone. (See comments above under RANDOM ACCESS TIME.) Very high performance drives, such as the ones listed in Table 1, have burst rates which exceed the transfer rates possible across their host interface. This interface is typically Fast SCSI-2, narrow, capable of 10 MB/s synchronous transfers. The sustainable continuous rate is below the highest media transfer rate and is primarily a function of the head switching time to address a new track without any actuator movement (below 1 ms), and of the single track access time (under 2 ms). These latter are overhead which detract from the possible media transfer rate to yield a net rate.

Magnetic tape drives are designed to optimally work with a data stream near their rated transfer rate. The time delays associated with running out of data to record and having to decelerate the tape, stop, back up, accelerate up to record speed, synchronize with the old data, and start recording again are severe penalties to pay for failing to keep a tape fed with data.

ON-LINE CAPACITY

Both RAM and Flash memory designs require some additional memory capacity for parity or other error detection schemes. Simple parity on a byte basis requires an additional 12% of memory capacity beyond the user data capacity. Flash memory systems frequently use a more powerful error correction and detection code, such as a Reed Solomon code. These codes are more efficient than parity in their use of additional memory.

Magnetic and magneto-optic disks and tapes also use powerful error correction and detection codes. The overhead associated with these codes is part of the difference

between capacity expressed as “formatted” versus “unformatted”. Small form factor disks and most tapes offer integrated data compression, a compression factor of “typically” 2:1 is described—actual compression achieved is pattern dependent. This integrated compression is, of course, lossless.

The 5.25" form factor optical disks are usually described by the total capacity of the media, side A plus side B. It is very unusual for a drive to be able to read both sides of the disk without intervention by some outside means to remove the disk, flip it over to the other side, and re-insert it. The capacity quoted is also associated with a 1,024 byte block size. Smaller user capacity (approximately a 13% reduction) is available when a 512 byte block size is used.

SUITABILITY TO TASK

Each of these storage technologies has particular strengths and weaknesses. Listed in Table 2 is a summary of these characteristics that can be used to choose a technology best suited to a particular application.

Table 2 Relative Strengths and weaknesses

TECHNOLOGY	STRENGTHS	WEAKNESSES
DRAM	Very fast random access Very high sustained read/write	High cost/MB Volatile, needs active refresh
Flash NAND	Fast random access High sustained read rate No shock/vibration isolation required Next generation chips use same pinout Very fast random access	High cost/MB Slow sustained write rate Wearout phenomenon must be managed No commonly accepted

TECHNOLOGY	STRENGTHS	WEAKNESSES
NOR	High sustained read rate No shock/vibration isolation required	declassification method High cost/MB Very slow sustained write rate Wearout phenomenon must be managed No commonly accepted declassification method Pinout changes between generations
Magnetic Disk	High sustained read and write rates Very low cost/MB Smallest volume per on-line capacity PCMCIA form factors intrinsically rugged Well suited to arrays for very high capacity and data rates	Slow random access times Very slow data destruct (triple overwrite)
Magneto-optic	Moderate cost removable media Well suited to jukeboxes for massive near-line capacity Media retains direct access properties	Moderate on-line cost/MB No non-destructive declassification method Relatively fragile under vibration and shock
Magnetic Tape	Lowest cost/MB removable media	Very slow access time Slow sustained transfer rates Fragile under vibration

INTRINSIC ENVIRONMENTAL RUGGEDNESS

Table 3 shows a summary of the commonly specified environmental characteristics associated with many of the technologies discussed here. There is little incentive within

the commercial computer industry to make claims for broader environmental performance except in those limited areas where consumer awareness is focused. Any such broader claims would increase production costs due to reduced yields, and with little marketing advantage. Given the negative net margins on which many storage device manufacturers operate, there is little chance of expanded specified limits unless it is demanded by the consumer.

Table 3 Representative Commercial Environmental Specifications

TECH- NOLOGY/ PARAMETER	1.8" MAGNETIC DISK	3.5" WINCHESTER (4.0 GB)	3.5" MO (230 MB)	5.25" MO (1.3 GB)	8 MM TAPE
SHOCK					
Operational	150 G, 2 ms	2 Gs, 11 ms, half sine 10 Gs, 11 ms, half sine (recovered errors permitted)	5 G, 11 ms, half sine 30 G, 3 ms, half sine	4 G, 11 ms, half sine 25 G, 3 ms, half sine	3 G, 5 ms 2 G, 11 ms 1 G, 20 ms
Non- operational	1000 G, 1 ms	50 Gs, 11 ms, half sine	35 G, 15 ms square pulse 89 G, 3 ms, half sine	35 G, 15 ms square pulse 60 G, 3 ms, half sine	40 G, 11 ms 30 G, 30 ms
Vibration (Sine)					
Operational	NA	0.5 G, 5-400 Hz	Not Available	Not Available	Not Available
Non- operational	NA	5-22 Hz @ 0.040 inches displacement 2 G, 22-400 Hz	Not Available	Not Available	Not Available
Vibration (Random)					
Operational	NA	Not Available	0.25 Grms (1-500 Hz).00015 G ² /Hz 5-350 Hz -6 dB/oct 350-500 .0001 G ² /Hz 500 Hz	0.45 Grms (5-500 Hz) .00015 G ² /Hz 5-350 Hz -6 dB/oct 350-500 .0001 G ² /Hz 500 Hz	.02 G ² /Hz 5-350 Hz -6 dB/oct 350- 500.0001 G ² /Hz 500 Hz

TECH- NOLOGY / PARAMETER	1.8" MAGNETIC DISK	3.5" WINCHESTER (4.0 GB)	3.5" MO (230 MB)	5.25" MO (1.3 GB)	8 MM TAPE
Non- operational	NA	Not Available	0.2 G ² /Hz 5-100 Hz -6 dB/oct 100- 137 Hz .01 G ² /Hz 137-350 Hz -6 dB/oct 350-500 Hz .0052 G ² /Hz 500 Hz	0.2 G ² /Hz 5-100 Hz -6 dB/oct 100-137 Hz .01 G ² /Hz 137-350 Hz -6 dB/oct 350-500 Hz .0052 G ² /Hz 500 Hz	.02G ² /Hz 5-100 Hz -6 dB/oct 100- 137 Hz .0107 G ² /Hz 137- 350 Hz .0052 G ² /Hz 500 Hz
Temperature					
Operational	5 to 55 deg C	5 to 50 deg C	10 to 40 deg C 5 to 40 deg C	10 to 40 deg C 5 to 40 deg C	5 to 40 deg C
Non- operational	-40 to 70 deg C	-40 to 70 deg C	0 to 60 deg C -30 to 60 deg C	1 to 60 deg C -30 to 60 deg C	-40 to +60 deg C
Relative Humidity	4% to 90%	5% to 95%	10% to 85%	10% to 85%	20% to 80%
	Integral Cobalt 420	ST15150	IBM MTA-3230 Sony SMO-E301	IBM 0632-CHA Sony SMO-S521	EXB-8500C

One example of broadening performance claims is the area of shock in magnetic disk drives. These devices have long had a well deserved reputation for fragility. Thus the consumer is very aware of the potential for damage and is concerned because they know the real world knocks to which their laptop is exposed. Thus compare the shock values specified for the 1.8" drives (used in PCMCIA cards) to those of the other devices. Further, consider the first 5.25" drive, the ST506, which did not even specify shock levels in its marketing information. It used an open loop stepper motor positioning system, gamma-ferric oxide media, and a carriage for the head assembly which was fraught with problems.

APPENDIX B — HIERARCHICAL STORAGE MANAGEMENT

HIERARCHICAL MANAGEMENT SYSTEMS

Hierarchical Storage Management (HSM) technique has been used on main frame systems for probably 20 years. Its applications to mid range, PC LAN, and PCs are relatively new, with the first commercially available packages introduced in 1992 and 1993. Current HSM systems can be divided into four different classes.

TURN KEY HSM FILE SERVERS

This class of hierarchical products is exemplified by the Epoch-2 Data Server from Epoch Systems. On a network, the Epoch-2 data server appears as a standard NFS mounted disk with massive storage. The data server provides from 20 to 100 Bss of storage in various combinations of disk, optical libraries, and tape libraries. Any client on the network can take advantage of Epoch as long as it can run NFS client code and use an NFS server. The data server automatically migrates inactive files to libraries from hard disks. While it typically migrates files, it also has the ability to break a large file into as many as 64 chunks and stage the files back to magnetic disk in chunks.

Very similar products are available from NETstor Corp. (NETstor server), from AT&T COMM Vault(DMS), and from the Discos division of General Atomics (Unitree server). Products in this category are generally UNIX-centric; they generally work for UNIX workstations and LANs, but do not work for, say, a Novell LAN.

HSM SERVER APPROACH

This approach is typified by the Conner HSM server from Conner Peripherals for Novell Netware LANs. The HSM server supports several Novell Netware file servers, migrating files from these file servers to the storage server as they age. The HSM server is a PC running Netware 3.11 and has disks, optical libraries, and tape libraries. Requests from user PCs go to the Netware file server where they are intercepted by special software. If the special software determines that the file being requested has been migrated to the HSM server, the request is sent to the HSM server. Otherwise, the special software passes the request to the normal file server code for usual processing. Special client code is also needed in each client machine to make use of the HSM server. Advanced Software Concepts has a product called NetArchive which also falls into this category, although it focuses on UNIX networks. The HSM server approaches are unique to one type of network; e.g., Netware or UNIX LAN. They are also file system specific and migrate entire files between workstations and the HSM server.

HSM FILE SYSTEM APPROACH

Unlike the previous two approaches which were turnkey approaches in which complete servers were sold, the hierarchical file system approach uses software to enhance the functions of existing servers. Epoch, for example, will unbundle and sell their EpochServ software separately if the customer already has a SparcStation running Solaris. The combination of the SparcStation running Solaris, libraries, and the EpochServ software is a file server which is similar to the Epoch-2 Server described earlier. NETstor also unbundles their software similarly to Epoch.

Hierarchical file systems fall into three categories. In the first category the software is used to produce a completely new hierarchical file system that coexists with the other file systems on the machine. Since the new hierarchical file system has a standard file system interface, all applications that run on top of the standard file system layer work unchanged. An example of a product in this first category is AMASS from Advanced Archival Products. AMASS runs on UNIX machines such as the Sun SparcStation, the IBM RS/6000, and the HP 9000.

The second category consists of software that is used to convert the local file system into a hierarchical one. Products in this category include those from Epoch and NETstor for Solaris on SparcStations, ARIA Server migration manager from Control Data for UNIX, and Network Archivist from Palindrome for Novell Netware.

The third category consists of software that is used to convert all of the file systems into hierarchical ones. An example of such a product is the Transmigrator from Lachman Technology for Solaris on SparcStation. It uses the technique of "stacking file systems" and sits on top of existing file systems, augmenting the "covered" file system's capabilities.

Hierarchical file systems are typically used on server machines. Many of the products mentioned above also have client code which is used to migrate data from client local disk to the server. Once at the server, the hierarchical file system migrates data between the server's disks and the server's libraries.

These hierarchical file systems have the disadvantage of working only for specific platforms, operating systems, and, in many cases, file systems.

DEVICE DRIVERS WITH MAGNETIC CACHING

CorelSCSI from Corel Corporation is the only known product in this category. It is a Novell Netware device driver for an optical library with magnetic disk caching. This is not a true hierarchical system since it uses the magnetic disk only as a cache, not as a permanent home for data. It is also specific to Novell Netware and does not work in other environments.

HSM DATA MANAGEMENT

New data management technology is emerging to further expand the hierarchical capability. One of the most promising of these technologies applies the philosophy of virtual memory to storage. It manages all storage devices on the system as virtual storage. This technology brings many advances to the small user including the following.

Self Tuning — The virtual storage implementation optimizes use of real disk space. This faculty dynamically changes which partition or file system is allocated more real disk space, depending on the age of the partition or file system's data.

File based HSMs manage real disk space in a static way. If a partition/file system has been allocated only one-half the disk, its data will be migrated to tape when the disk is one-half full, even when the other half of the disk has very old data, or no data at all. Dynamically optimizing use of real disk space via virtual storage provides a performance advantage similar to that achieved by the virtual memory concept for CPU main storage because it is able to manage all of the system memory.

Balanced Performance — System performance can be increased to meet customer expectation by adding real disk space. Virtual storage automates the use of additional space without outside intervention resulting in improved performance. File based HSMs on the other hand require the modification of the policies in order to use the new disk to improve performance. One could manually create a new partition/file system on the new disk, then manually choose to transfer some of the old data from the old disk to the new disk (possibly requiring application changes). Typically, the new disk would be used to hold an increase in data capacity; the increase would remain unused until new data were created and stored on the new disk.

Plug and Play — The installation of a virtual storage feature is as simple as installing a new device driver or adding a new disk. It would be delivered with a set of simple defaults which will perform adequately for most customers. File based HSM installation is similar to installation of more complex software and requires many parameters and policies to be properly defined and set.

Total Support — File based HSMs do not support applications such as database managers which do raw disk I/O (and do not use file systems). Depending on how they are implemented, they may be able to support only one file system (say FAT), and applications that use another file system (say HPFS), are not supported. In a multiple application environment some of the applications may use a database manager that does raw I/O and other applications may use a file system not supported by the file based HSM. In this scenario, a virtual storage implementation will still be able to support all of the applications, whereas the file based HSM can only support some of the applications.

Uninterrupted Growth — No modification is required to a virtual storage implementation with the installation of additional applications. (Additional real DASD

may be required to maintain the performance level.) File based HSM systems would require a modification to the policy parameters.

Openness — As the customer grows and adds applications with a file based HSM system, he must ensure that support is available for the application. A virtual storage implementation provides more flexibility because it is application independent.

Consistency — In a multiple application environment, the end user will have consistency in data retrieval. If a file based HSM system is installed, unsupported applications would need manual archive/recall procedures while supported applications would be handled automatically by the HSM.

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